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METAL PROCESSING

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Second Edition

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Dedicated to

WILLIAM BOSTON

London Society of Engineers and Machinists

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1835

PREFACE

This textbook is for college use, but will serve also for industrial or short courses dealing with machine tools, cutting tools, and machinability. In view of the many illustrations of basic and special machine tools, typical machining operations, and comprehensive recommended practice, it should be of use to production, tool, and design engineers, superintendents, foremen, and draftsmen.

This book is the result of thirty years of teaching upperclassmen of mechanical and aeronautical engineering at the University of Michigan.

Metal Processing has been completely revised. The chapter on die casting and plastics has been removed to make it possible to add a chapter on surface quality and appreciably enlarge the chapters on machinability, machine tool drives, covering electric motors, and hydraulic pumps, both with their controls and circuits. Much of the information dealing with sintered-carbide tools and their use is new.

The steps involved in designing for production are covered in the first chapter. The manufacturing drawing with tolerances and surface quality indicated, the analysis and form of material used, the machining operations indicated, the machine tools, cutting tools, and accessories for manufacture and inspection determine the final plant layout. Subsequent chapters treat in detail the various classes of machines, processes, and factors involved so that the student develops the ability to plan from its drawing the production of a part for various conditions of quantity and quality.

This book emphasizes particularly the nomenclature of tools and the subject of machinability. Extensive data are given to show cutting forces, power, tool life, chip formation, and surface quality as influenced by the properties of the material being machined, the cutting fluid, and the tool shape and quality. The results of original investigation and practice are coordinated.

In these times it is gravely important that design engineers conserve strategic metals and simplify and refine designs so that machines and parts can be produced most efficiently and at reasonable cost, or, in case of emergency, at sufficiently high rate to meet any need. One of the most effective means of accomplishing such ends is for engineers to keep abreast of all the latest processes and materials so as to develop and use their machines with these purposes constantly in mind.

In the present tremendous expansion of tool design and producti the wide range of specific practical recommendations covered sh find immediate use. If this reduces loss of time and unnecessary pense in this field, I shall be profoundly gratified.

Many of the features of machine tools, accessories, and cutting to as illustrated and described, are protected by United States and for patents. Attention has not been drawn to each instance. S patented features are shown for general educational purposes with permission of the manufacturer, to whom specific acknowledgm is made.

The many individuals and industries furnishing data and illustratio have been most cooperative. Lack of space alone prevents mention them by name.

O. W. Boston

January, 1951

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CHAPTER I

AN INTRODUCTION TO THE STUDY OF MACHINES, TOOLS, AND PROCESSES

Metal processing deals with machine tools, small tools, accessories, and processes by which the production of parts or devices is accomplished in single units, small quantities, or mass production. Equipment for the production of parts in small quantities is usually so constructed that it can be adapted to a wide range and variety of work, and requires well-trained operators. Equipment for the production of parts in large quantities, on the other hand, more often is made as a single-purpose machine, simpler in construction, or with automatic features and provided with accessories so that an operator with little education or training can load the work into the machine, pull a lever to start it, and later remove the machined work. These machines increase the rate of production, improve the quality of the product, and reduce the manufacturing cost. Machine tools and accessories of a wide variety are in use, the types and designs of which bear a definite relation to the product.

Design for Manufacture

In order to produce most effectively a serviceable product, readily salable at low cost, its design, metallurgy, and production must be correlated carefully. There is a very sensitive relationship among these three factors which may be obtained most satisfactorily in an organization complete in itself by following a method of procedure suggested in Table 1.

Many times a product is designed or developed by one person and then turned over to a second for its production. Competitive bidders may not set forth the ways and means of manufacture unless specifically asked to do so.

Planning the product: In planning the design of a product, it is usually the best procedure to start by making a series of rough sketches or layouts, as indicated by 1, Table 1, to establish in the designer's mind definite values of proportions, size, appearance, and mechanical perfection. Even in those projects involving the mass production of comparatively inexpensive items or the low production of relatively

TABLE 1. STEPS IN PLANNING THE DESIGN AND MANUFACTURE OF A PRODUCT

Design

1. Prepare rough sketches of the assembly and the various component parts.
2. Select the type (analysis) of material to be used for each part.
3. Select the fabricated form (bars, sheets, forgings, castings) of material.
4. Determine the heat treatment or other treatments (annealing, hardening, plating, nitriding, cyaniding, etc.) of material for purchasing, machining, and finishing the product.
5. Make computations for strength and rigidity, and review various parts for uniformity of sections, fillets, proportions, appearance, etc.
6. Prepare finished manufacturing drawings incorporating all features of design, select fits, show dimensions, tolerances, material, surface quality, and hardness for each part.

Manufacture

Prepare routings for each part, considering the number of parts to be produced. Set forth all operations in sequence to give the required accuracy and finish at the lowest possible cost, and indicate for each operation the machine tool, cutting tools, cutting fluids, jigs, fixtures, dies, measuring instruments, and gages to be used.

8. Design and make manufacturing tools and accessories:
   (*a*) Patterns for parts to be cast.
   (*b*) Forging dies for parts to be forged or upset.
   (*c*) Press dies for parts stamped or drawn.
   (*d*) Dies for die casting, plastic molding, powder metallurgy, etc.
   (*e*) Jigs, fixtures, and other accessories needed in manufacture.
   (*f*) Measuring instruments and gages for quality inspection.
   (*g*) Cutting tools and machine tools.
9. Determine the production time for each operation and the number of machines of each kind required to provide the desired rate of production.
10. Prepare the complete plant layout and indicate the flow of material.

expensive items, a thorough analysis at this point is very much worth while. Rough layouts frequently may be followed by the preparation of miniature or full-scale models. From such studies the designs may be revised.

Selecting the material: As soon as the general size and shape of the article are decided on, the next step, 2 in Table 1, is to select the type of material of which each component part should be made. If one inexpensive device is needed, the designer may provide sketches bearing only important dimensions and, after explaining the use of the device, leave the selection of materials, fits, and tolerances to the convenience or judgment of the builder. Sometimes the designer specifies those materials used in a previously built machine similar in general design and purpose, in which, by cut-and-try method, unsuitable and expensive materials have been eliminated. If great cost or many parts are involved, every care should be given to the selection of the materials best suited for each part to meet keen competition. Many materials, as suggested in Table 2, are in common use, and following chapters discuss specific applications in more detail.

TABLE 2. MATERIALS USED IN ENGINEERING CONSTRUCTION

1. Aluminum and its alloys, AlCo, ASTM and SAE Standards.
2. Plastics, resinoids: cast, molded, or laminated.
3. Carbides: tungsten, tantalum, titanium, boron, aluminum, silicon.
4. Carbon, graphite.
5. Copper-nickel alloys (Monel).
6. Copper-tin alloys (bronze), ASTM and SAE Standards.
7. Copper-zinc alloys (brass), ASTM and SAE Standards.
8. Cork and sound-deadening and heat-insulating materials.
9. Fabrics, leather, paper, etc.
10. Glass, Pyralin, ceramics.
11. Glues: animal, blood albumen, casein.
12. Hard rubber, asbestos, fiber, carbon, etc.
13. Iron, cast: plain, alloyed, and fine spheroidal graphitic.
14. Iron, malleable: black heart malleable, pearlitic iron, etc.
15. Iron, white.
16. Iron, wrought.
17. Lead, tin, zinc, antimony, and their alloys, ASTM and SAE Standards.
18. Magnesium and its alloys, ASTM and SAE Standards.
19. Paint, enamel, varnish, lacquer, japan finishes, dopes, and metal-plating, etc.
20. Powder metallurgy.
21. Rubber, hard or flexible.
22. Steel, cast: including many alloys.
23. Steels, SAE and AISI classification.
24. Steels, stainless and heat resistant of several varieties.
25. Steels, 13 per cent manganese.
26. Steels, high temperature.
27. Steels, nitriding.
28. Steels, tool.
29. Steels, miscellaneous types.
30. Cast nonferrous metals, as Stellite.
31. Wood, plywood, and wood-metal.
32. Zinc and its alloys, die castings.

Some properties of major importance are strength, modulus, ductility, hardness, weight, resistance to wear, corrosion, friction, heat, electrical resistance or conduction, machinability, and appearance or sales appeal.

In many instances, the material best suited to a given part is not available, is too expensive, or is too difficult to work, so a compromise may be necessary in favor of a second or third choice. The cheapest material actually may involve greater manufacturing cost than a more expensive material. For this reason, free-cutting brass rod often is used in screw-machine work for making small parts requiring no appreciable strength, in preference to much less expensive free-machining steel, as higher cutting speeds can be used. Low initial cost of the metal does not necessarily lead to low final cost of the article produced.

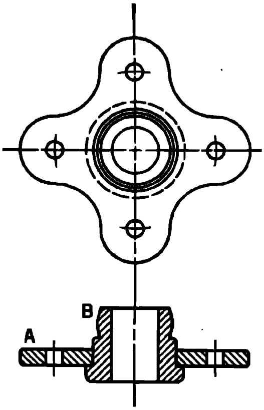


FIG. 1. A Sketch of a Part Which Can Be Made of Any Metal Fulfilling the Physical, Chemical, and Thermal Property Requirements by Forging, Powdered Metal, Molding, or Casting as a Unit, or by Welding, Brazing, Rolling, Threading or Force-Fitting a Bar Stock Product with a Stamped Sheet Product of Like or Unlike Materials, each Part Selected on a Basis of Costs, Availability, or Property.

Figure 1 shows how even a simple part can be made by combining two parts of unlike metal processed differently to gain advantages in cost, properties, or speed of production, or to make use of available equipment.

There are many **steels** of various chemical compositions, standardized by the American Iron and Steel Institute (AISI). The Society of Automotive Engineers (SAE) has accepted many of these for use in the automotive industry. These do not include the many types of stainless and heat-resisting steels, carbon and alloy steel castings, cast iron, malleable cast iron, and hundreds of various alloys of nonferrous metals and nonmetallic materials employed by that and other industries. All these are standardized by the ASTM, SAE, Army, Navy, etc. Many new metals are being added to this group each year to meet the constantly increasing demand for greater strength, hardness, wear, and corrosion resistance, as well as immunity to the deleterious effects of high temperatures.

The steel compositions included in the **standard specifications** of the Society of Automotive Engineers are considered adequate for practically all parts made of ferrous materials, which are necessary for the production of automotive apparatus. A numerical index system representing the specifications is used, which makes it possible to use the index on shop drawings and blueprints. This index is partially descriptive of the quality of the material covered by SAE numbers, as indicated on page 5 (compositions in percentages).

The first digit at the left indicates the class to which the steel belongs. Thus, 1 indicates a carbon steel; 2 a nickel steel, etc. In the case of the alloy steels, the second figure generally indicates the

Carbon Steels: SAE	1010	low-carbon, deep drawing steel, 0.10 C, 0.10 S.
	1020	low-carbon (mild or machinery), 0.20 C.
	1120	high-carbon (sulphur) free-cutting, open-hearth.
	1112	low-carbon (sulphur) free-cutting, Bessemer.
	C1116	free-cutting with 1.10–1.40 Mn, 0.16 C, 0.20 S.
	1340	Mn steel with 1.60–1.90 Mn, 0.40 C, 0.04 S.
Nickel Steels:	2345	heat-treating, 3.5 Ni. 0.45 C
	2515	carburizing, 5 Ni, 0.15 C.
Nickel-Chromium Steels:	3115	carburizing, 0.55–0.75 Cr, 1.00–1.40 Ni.
	3316	carburizing, 1.40–1.75 Cr, 3.25–3.75 Ni
Molybdenum Steels:	4130	heat-treating, 0.15–0.25 Mo, 0.80–1.10 Cr.
	4615	carburizing, 0.20–0.30 Mo, 1.65–2.00 Ni.
Chromium Steels:	5140	heat-treating, 0.70–0.90 Cr.
	52100	heat-treating, about 1.3–1.6 Cr, 1 C.
Chromium-Vanadium Steels:	6150	heat-treating, about 1 Cr, 0.18 Va.
Silico-Manganese Steel:	9260	heat-treating, 1.80–2.20 Si, 0.70–1.00 Mn.
Corrosion- and Heat-Resisting Alloys:	30915	17–20 Cr, 8–10 Ni.

approximate percentage of the predominant alloying element. The last two figures indicate the average carbon content in hundredths of 1 per cent. Thus, SAE 2345 indicates a nickel steel having approximately 3 per cent nickel with 0.45 per cent carbon.

There are thirty AISI standard types of **stainless** and heat-resisting steel, divided into three general categories, martensitic, ferritic, and austenitic types. The austenitic alloys contain both chromium and nickel, with both elements classified as major constituents. AISI 302, 303, 304, 309, 316, 321, and 347 are typical compositions of this group. They have their maximum corrosion resistance in the annealed state. The martensitic group, of which AISI 410, 416, 420, 431, and the 440 series are typical, has chromium as the major alloying element. These grades are magnetic and respond to heat treatment, in which condition they have maximum corrosion resistance. The ferritic group, typified by AISI 430, 430F, and 446, also contains chromium as a major alloying element. These steels are nonhardenable and magnetic, and they display maximum corrosion resistance in the annealed condition ("Machining Stainless Steel," by L. F. Spence, *The Iron Age,* July 7, 1949, p. 83).

Selecting Fabricated Form of Material

Most materials are fabricated into convenient forms for use as listed in Table 3. Many materials are hot or cold finished into **bar stock** by drawing through a die or by extrusion. These bars are subsequently machined in lathes, turret lathes, screw machines, and automatics, depending on quantities of parts to be produced.

Castings of any metal can be made in almost any size and in simple or complicated shapes. They must be resorted to when intricate shapes are to be produced. Metal can be poured into green-sand molds, dry-sand cores, or permanent metal molds to suit the size and shape of the work and the quantity required. Castings must be machined to final size if close dimensional control is desired.

Die castings are limited to low-melting-point metals, such as alloys of lead, tin, zinc, magnesium, aluminum, and copper, but are made in limited sizes and weight. The molten metal is forced under pressure into metal molds. Dimensions of die castings can be held to within 0.001 in. per in. of length. Holes can be cored, threads cast, and smooth surfaces provided so that little, if any, machining is required to prepare the casting for use. Only light polishing or buffing is necessary before plating.

TABLE 3. FORMS IN WHICH VARIOUS MATERIALS MAY BE OBTAINED

Standard Shapes

Rolled structural shapes, as beams, angles, T's, I's, and channels.
Plates over 3/16 in. thickness.
Sheets under 3/16 in. thickness.
Strips, hot or cold finished.
Bars over 1/2 in. diam., hot or cold finished.
Wire under 9/16 in. diam.
Tubes, welded and seamless.
Extruded shapes.

Selective Shapes

Die forgings and upsettings.
Green sand, permanent mold, and precision castings.
Die castings.
Molded plastics and resinoids.
Sintered pressed powdered metal.
Stampings.

Powdered metal is now being formed into symmetrical parts by being compressed in a die and subsequently sintered. Unique properties such as porosity required by oilless bearings or graphitic bearings, high accuracy, and good surface quality are obtainable. This process is now competitive with other processes for high production, such as machining, die casting, precision casting, stamping, and forging.

Forgings from dies represent, for most metals, the strongest and most reliable form in which the metal can be prepared. They can be made close to size to reduce machining, but are limited to more or less simple shapes of comparatively small sizes not exceeding two or three hundred pounds. Forgings, heat treated after machining, provide very high strength.

Stampings as produced by means of press tools from sheets or strip metal combine high strength and light weight. With the wide variety of presses available and the opportunity for building so many types of dies, very complicated parts can be made in almost any size in large quantities at relatively low cost. These die operations consist essentially of blanking, punching, and forming. Very little subsequent machining is required.

Spinning is a low-production or special finishing operation to form sheet metal into final shape. The rotating or formed sheet is forced over a preformed chuck or form of wood or metal by a manually or mechanically operated round-end tool. The tools and chucks are less expensive than press dies, but the unit labor cost is high.

Machining from bar stock in lathes, screw machines, or automatics is a cheap way of producing parts of symmetrical shape and circular section. The bars may be hot or cold finished and round, square, hex, etc., as desired. The material cost is low, but the machining cost may be relatively high. Special types of screwstock, steel, brass, aluminum, etc., are made for large-production service.

Welding or **induction brazing** by itself or in conjunction with any of the above processes lends itself very satisfactorily to producing parts at a high rate and low final cost.

Metallizing is a process of depositing one metal on another to build up a worn part or to provide special surface properties. A wire of the metal to be deposited is passed through a gun often held in the tool post of a lathe as the work rotates. The wire end adjacent to the work is melted in an oxygen-acetylene flame and blown against the work as an atomized spray.

Electroplating is also used to repair or surface small parts for specific purposes. Many **nonmetallic** materials, manufactured under hundreds of trade names, are essentially organic **plastics,** such as resinoids, cellulose, protein, casein, and rubber. They are molded in metal molds and used for a great variety of products. The molds are expensive, and, therefore, mass-production quantities are required. The molds are mounted in machines quite similar to die-casting machines in which the parts can be heated and compressed simultaneously.

These materials are divided into two types: the **thermoplastics** and the **thermosetting.** The **thermoplastics,** which soften when heated and harden when cooled, even repeatedly, consist of casein plastic (trade name, Karolith, Ameroid), cellulose acetate (Tenite), cellulose nitrate (Pyroxylin), ethyl cellulose, methyl methacrylate (Lucite, Plexiglass), vinylite resinoids, polystyrene, shellac, etc.

Thermosetting materials are those which soften while heating, but upon continuous application of heat are cured by polymerization and become permanently hard. These consist of phenolic resinoids (Bakelite, Durez, and Catalin), urea-formaldehyde (Beetle and Plaskon), hard and soft rubber, etc. Products from these various plastics and rubber are made by molding in metal dies, laminating with wood, canvas, linen, paper, etc., in large presses with steam-heated platens, extruding the material, or casting. Parts are molded by two principal methods.

Injection molding is applied to thermoplastic material, which in the form of granules is fed from a hopper on the machine into a cylinder which is externally heated. The material reaches a temperature of 300–400° F at the nozzle through which it is forced into the die under a pressure of several thousand pounds per square inch by a piston operated mechanically or hydraulically. The hot plastic comes in contact with the water-cooled walls of the mold and cools rapidly.

In **compression molding** the plastic resinoid is mixed with a filler, such as wood flour, asbestos, mica, or graphite, and a coloring matter, if needed. The mixture is made homogeneous and placed in a mold; the mold is closed under a temperature of 270–375° F and a pressure of 2,000–8,000 psi, depending upon the material and size and shape of the part molded. It is then molded and in a few seconds removed from the mold. The molds may have single or multiple cavities, and they may be of the overflow (flash) or of the positive type (no flash). The laminated material can be formed into sheets, tubes, and rods and subsequently re-formed in dies or machined to shape and size. Lamellar sheets are many times fabricated into gears which operate noiselessly and withstand heavy loads.

Discussion of Materials and Their Forms

When the quantity of parts to be produced is small, they may be machined from solid stock or built up from sheet, tube, and bar stock, joined by various methods, such as riveting, welding, brazing, and soldering. Above a certain quantity, these methods of construction become prohibitive owing to expense, and production processes of casting, forging, and stamping are employed. To illustrate, one part may be machined from solid stock or built up at a cost of $10. If ten of these parts are required, it may be worth while first to make a pattern of wood at a cost of $30, from which ten green-sand castings can be made at a total cost of $5. Subsequent light-machining operations may cost an added $25, making a total cost for ten parts of $60, or a final cost per piece of $6. However, if 100 pieces are required, a good metal pattern may be made, which costs more than the short-lived wood pattern, but whose cost, when prorated over 100 pieces, is less per piece. Refinement in the machine-tool setup would reduce the unit cost of machining, while the material cost per piece would remain the same. The result is that each of the 100 pieces costs less than one of the ten. If greater quantities are required, other fabricating processes, such as die forging, stamping, or die casting, may be found to reduce the material cost and eliminate most of the machining formerly required. The high cost of the dies prorated over the thousands of parts made would result in a very low unit cost.

If parts of brittle cast iron are found to break repeatedly, they are replaced by ductile malleable cast-iron or high-strength steel castings or forgings. Weight imposes limitations, and ductility is of great importance. The designer of heavy machine tools, rolling mills, etc., is more interested in rigidity than in saving weight. Therefore, cast-iron, cast-steel, and plain carbon-steel forgings are commonly used. The beds of machine tools, the frames of electric motors, and many like devices are made of heavy cast-iron pieces, or they may be built up from structural-steel shapes and sheets by the process of riveting or welding. Welding is gaining in favor as a substitute for riveting. High-pressure tanks, ships, bridge and building structures, machine tools, and jigs and fixtures are being constructed of steel sheets, plates, and structural shapes welded, riveted, or screwed together.

Low cost, low modulus of elasticity, ease of producing complicated shapes, low shrinkage, good machinability, and wearing qualities characterize **cast iron.** It is usually selected for cylinders for engines and compressors because of its good wearing qualities. Cast iron is produced in many ways and in many grades. The International Nickel Co. recommends a total of fifty alloys of nickel or nickel and chromium for specific uses. Molybdenum, chromium, vanadium, titanium, and other alloying elements also are used advantageously. Where greater ductility is required, malleable cast iron is used. The new cast iron containing very fine spheroidal graphite has a tensile strength and elongation approaching those of cast steel. It seems destined to replace many of the cast irons, malleable cast irons, and possibly even some cast steels (*Iron Age,* Feb. 17, 1949).

Cast steel is substituted where a stronger material is required or where lower weight is essential. **Steel forgings** for parts in quantities of comparatively simple shape and limited weight replace steel castings. Forgings containing various alloying elements, when properly heat treated, furnish the most desirable physical properties.

The designer of automobiles and airplanes is interested in high strength-weight ratio and, therefore, uses high-strength alloy steel heat treated, high-strength light alloys of aluminum and magnesium, and, where possible, sheet steel formed to the desired shape. Large parts are built up of sheet steel by riveting or welding. Forgings of steel are used where practicable instead of castings. Cast iron is replaced by the stronger and more ductile steel castings, except for use as cylinder blocks or pistons. Where the machine involves high speed and high power, alloy steels are introduced for gears, shafts, etc.

Additional materials used in aircraft construction are canvas, linen, silk, leather, wood, plywood, glues, rubber, and sound-deadening and heat-insulating compositions. Airplane ribs and wings may be made up of nailed and glued wood structures, riveted aluminum alloy shapes, or shot-welded stainless sheet-steel shapes. The fuselage and landing gear usually are made up of welded steel tubing, with the highly stressed members of chromium-molybdenum steel, SAE 4140, while the lower-stressed tubes are of plain medium-carbon steel, SAE 1030, both of which have good welding properties. Sometimes riveted Duralumin sheet, 17ST, is used. Gasoline tanks are made of welded pure aluminum sheet.

Plastics and resinoids having a large variety of properties and of many types are available. In general the tensile strength is 4,000–10,000 psi. They are brittle, usually good nonconductors of electricity, and corrosion resistant. They can be produced in many attractive colors and finishes at prices which make them active competitors of stamped, cast, die-cast, forged, machined, and sintered powdered metal parts. Novelties, trimmings, buttons, ladies' belt buckles, and a variety of colored parts are made by casting, molding, and extruding rods and tubes of **casein** plastics. Soft-**rubber** parts are made by molding rubber gum to which has been added about 10 per cent of sulphur as a vulcanizing agent. By adding a greater amount of sulphur together with inert mineral fillers to the gum, the molded part becomes hard rubber. This is strong and ductile and is good for parts such as telephone receiver shells, which receive rough handling. Hard rubber is also molded into rods and sheets and subsequently machined for flashlight cases and vacuum-cleaner parts. **Urea-formaldehyde** molding plastic is very much like phenol-formaldehyde and has a natural, translucent ivory color which permits light coloring pigmentation. It is premolded into tablets and finally molded in metal dies. It is resistant to water, acids, oils, etc., and has great dielectric strength.

It is used extensively for teacups, tumblers, plates, clock cases, vacuum-bottle caps and cups, etc. **Phenol-formaldehydes** are blended with fillers such as wood flour and molded into parts requiring lightness, superior finish, and good mechanical strength. **Cellulose nitrate** is inflammable, its principal disadvantage. Sheets softened in solvents can be shaped or drawn in dies. Tubes may be expanded by high-pressure steam to fill the cavity of the mold. Toy animals and rattles are made by this method. It has unlimited color possibilities and is used in making combs, toilet-article handles, etc. **Cellulose acetate** is used considerably for making parts such as clock cases. It is available in sheets, rods, and tubes or as a powder which is used for making tablets for molding. One form of cellulose acetate (Tenite, Butyrate) has high ductility.

Parts may be made for high production from **powdered metals** of almost all types by compressing them in metal dies under high pressure and then sintering them. The structure of the metal can be controlled to make it dense or porous. Many small parts, symmetrical in shape so as to be produced in compression dies, can be made by this method. Bearing bushings containing oil in the porous structure for oilless types of bearings, or the metal containing powdered graphite for use in high-temperature, oilless bearings, are readily made by this method.

Coordinated design: The design of a product is developed by the engineer of design and, because of the many factors involved, must be done in close cooperation with other divisions. Modern industrial plants comprise many departments or divisions, each having specialized work as shown in Fig. 2. Those most concerned with the details of design are:

1. The purchasing department — responsible for material procurement and costs.
2. Metallurgical department — set up and maintain specifications for materials.
3. Plant equipment department — furnish and maintain machine tools to machine the parts.
4. Tooling departments — furnish and maintain work-holding jigs and fixtures, dies, inspection gages, and cutting tools.
5. Production department — responsible for manufacturing.
6. Inspection department — maintain quality of the incoming material and product.
7. Sales department — establish and maintain markets for the product and provide a definite and uniform manufacturing schedule.
8. Industrial designer — responsible for sales appeal.

These offices agree on the material of which each part is to be made; the form in which that material shall be purchased; the treatment to which it is to be subjected to meet physical, thermal, or chemical requirements; features of design which influence the use of machine tools available or to be purchased; features of design, such as locating points, which influence the design of jigs, fixtures, and cutting tools in production, and practical manufacturing tolerances on dimensions. The design should provide for ease of assembly, repair, or replacement of parts so that the article may be produced and serviced at the lowest possible cost.

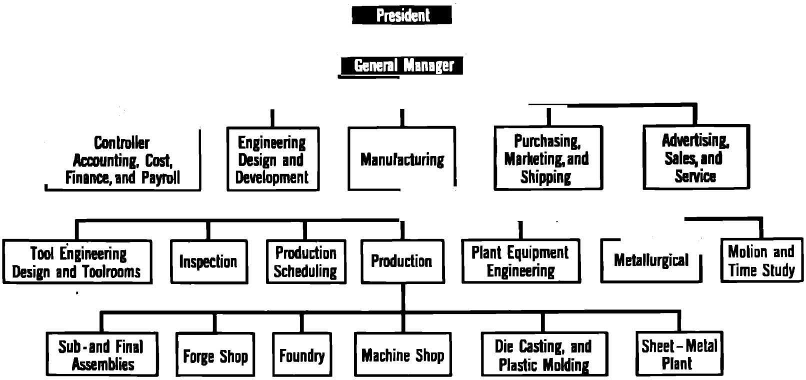

President
General Manager
Controller Accounting, Cost, Finance, and Payroll
Engineering Design and Development
Manufacturing
Purchasing, Marketing, and Shipping
Advertising, Sales, and Service
Tool Engineering Design and Toolrooms
Inspection
Production Scheduling
Production
Plant Equipment Engineering
Metallurgical
Motion and Time Study
Sub-and Final Assemblies
Forge Shop
Foundry
Machine Shop
Die Casting, and Plastic Molding
Sheet-Metal Plant

FIG. 2. An Organization Chart of a Manufacturing Plant Illustrating the Coordination of the Five Main Divisions As Well As the Subdivisions of Manufacturing.

Fits and tolerances: In designing, mating parts should be dimensioned in such a way that, after they have been made as individual units, they will fit together and function as desired. This is known as the **manufacture of interchangeable parts.** Frequently in job-shop work assemblies are built up by making one part to fit the other. This often requires long, tedious fitting operations. When occasional assemblies of high precision are desired, they are often obtained by **selective assembly** of parts from regular production.

No part can be made to fit another part exactly, nor can all pieces of any part be machined to the same exact size. The American Standards Association Standard B4a, 1925, provides for eight **metal fits** as illustrated in Fig. 3.

The **nominal size** is that size indicating a close approximation to a standard size, such as 1/8, 1 1/4, 2 1/16. The nominal size of the shaft and hole in Fig. 4 is 3 in. The **basic size** is the exact theoretical size from which all limiting variations are made, as 3.0000 in., equal to the nominal size for the hole, and 2.9981 in. for the shaft, equal to the basic hole size minus the allowance as shown in Fig. 4.

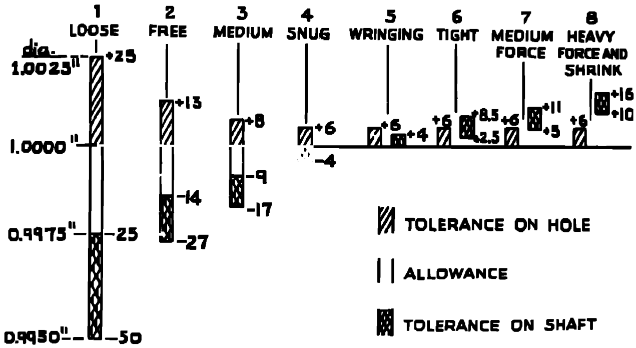


FIG. 3. The Eight ASA Fits for Parts of a Nominal Size of 1 in. Referred to the 1-in. Basic Size of Hole.

The basic size of shaft varies with the fit. The values representing tolerances are in 0.0001 in. With d representing the nominal size, and A, B, and C the constants for different classes of fits:

$$\text{Hole tolerance} = A\sqrt[3]{d}$$
$$\text{Shaft tolerance} = B\sqrt[3]{d}$$
$$\text{Allowance} = C\sqrt[3]{d^2}$$

Class 1, loose fit, large allowance. The constants A, B, and C equal 0.0025.

Class 2, free fit, liberal allowance. For running fits with speeds of 600 rpm or over, and journal pressures of 600 psi or over. A and B equal 0.0013. C equals 0.0014.

Class 3, medium fit. For sliding fits and running fits with speeds and pressures under those of Class 2. A and B = 0.0008, and C equals 0.0009.

Class 4, snug fit, zero allowance. The closest fit which can be assembled by hand. It necessitates work of high precision. It is used where no perceptible shake is permissible and where moving parts are not intended to move freely under a load. A equals 0.0006, B equals 0.0004, and C equals zero.

Class 5, wringing fit, with zero to negative allowance. Assembly is usually selective and not interchangeable. A equals 0.0006, B equals 0.0004, and C equals zero.

Class 6, tight fit, with slight negative allowance. Light pressure is required to assemble these fits, and the parts are more or less permanently assembled. A equals 0.0006, B equals 0.0006. Average interference equals $0.00025d$.

Class 7, medium force fit, with negative allowance. Considerable pressure is required to assemble these fits, and the parts are considered permanently assembled. These fits are the tightest recommended for cast-iron holes or external members, as they stress cast iron to its elastic limit. A equals 0.0006, B equals 0.0006. Average interference of metal equals $0.0005d$.

Class 8, heavy force and shrink fit, with considerable negative allowance. A equals 0.0006, B equals 0.0006. Average interference of metal equals $0.001d$.

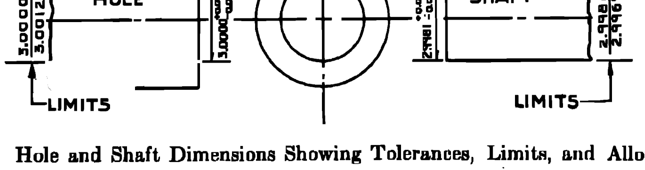


FIG. 4. Hole and Shaft Dimensions Showing Tolerances, Limits, and Allowances for a 3-in. Nominal Diameter with the ASA Medium Fit, Class 3.

This fit is used for running fits under 600 rpm and with journal pressures less than 600 psi; also for sliding fits and the more accurate machine tool and automotive parts.

The tightest fit is with the 3.0000-in. hole and the 2.9981-in. shaft, giving 0.0019-in. allowance.

The loosest fit is with the 3.0012-in. hole and the 2.9969-in. shaft, giving 0.0043-in. clearance which equals the allowance plus both tolerances.

The **allowance** is the intentional difference in basic diameters of mating parts to provide for different classes of fits. It is the minimum clearance space intended between mating parts made by the unilateral tolerance system, as 0.0019 in. in Fig. 4. It represents the condition of tightest permissible fit, that is, the largest internal member mated with the smallest external member. The basic hole is usually the nominal size, and that of the shaft is undersize. On this basis, standard reamers may be used to finish the holes. The shaft size is varied to suit the fit. The basic shaft may be used as the nominal size, however, and the hole diameter varied.

By **tolerance** is meant the amount of variation permitted from the basic dimension. Tolerances make it possible to manufacture parts accurately enough to function properly and to avoid unnecessary precision which would increase manufacturing cost without a proportionate increase in the practical value of the product. Figure 4 shows tolerances applied to the basic diameters of the hole and shaft. The tolerance on the hole is above the basic size, but that on the shaft is below unless for force fits.

There are two systems of tolerance in common use: the unilateral and bilateral. The **unilateral tolerance** system, as approved by the American Standards Association, Fig. 4, gives tolerances on only one side of the basic dimension. The bilateral tolerance system indicates tolerances on both sides. Tolerances are sometimes referred to incorrectly as limits. **Limits** represent the maximum and minimum dimensions, as shown in Fig. 4.

There are several American Standard forms of **screw threads** in general use, although the new United States, Canadian, and British Unified System will supplant them. The present systems consist of the American National Coarse NC series, the American National Fine NF series, the American National 8-, 12-, or 16-pitch thread series N, and the American National pipe thread series, tapered and straight. See Tables X-9, X-10, and X-11. Each ASA thread series is made in four classes: Class 1, loose fit; Class 2, free fit; Class 3, medium fit; and Class 4, close fit. Tolerances and allowances are given in specific tables in the above standard.

The new Unified Thread Standard (ASA B1.1, 1949) adopted by the United States, Canada, and the United Kingdom is based on a 60 deg thread with a flat crest and rounded root. Figures X-66 and X-67 and Table X-11 show the new thread standards. To correct irregularities prevalent in the old standard, the tolerances for the thread classes in the new standard are computed by formulas based on D, basic major diameter; p, pitch; and L_e, length of engagement.

New classes of fit for external threads are 1A, 2A, and 3A, and internal threads 1B, 2B, and 3B have been established to replace the old ASA Classes 1, 2, and 3. The tolerances on the internal threads are plus from basic, and the tolerances and allowances of the external are minus from basic. Thus there can be no interference between threads, regardless of what classes of thread are assembled. Class 2A is the recognized standard practice for production of screws, bolts, and other threaded fasteners. It provides clearance with any class of internal thread; it minimizes galling and seizing and high-cycle wrenching and high-temperature application. It accommodates plating when required. Old Classes 1 and 4 have been discontinued. The notation ⅜–16 UNC–2B, as shown in Fig. 5, means a ⅜ in. diam., 16 threads per in., Unified series, Class 2B fit. The Unified threads given in Table X-11 are designated as follows:

UNC: Coarse Thread Series for sizes ranging from ¼ to 4 in. diam., inclusive. Classes 1A, 1B, 2A, 2B, 3A, and 3B.

UNF: Fine Thread Series for sizes ranging from ¼ to 1½ in. diam., inclusive. Classes 1A, 1B, 2A, 2B, 3A, and 3B.

UN: Selected Special Thread combinations for diameters ranging from ¼ to 6 in., inclusive, and applying only to Classes 2A and 2B.

The terms applied to the Unified threads are illustrated in Figs. X-76 and X-77.

Manufacturing design: Finally, detailed and assembly drawings are prepared on which all features of design, including necessary mathematical calculations or practical considerations for convenience of manufacture, are incorporated. The detailed drawings of each component part are made to show all dimensions, class of fits, tolerances, concentricities, surface quality, and other instructions necessary for its manufacture, as illustrated in Fig. 5. Surface finish of the 0.874 in. diam. has lay marks perpendicular to the boundary line, of 8 microinches, root-mean-square surface quality, a waviness height not in excess of 0.005 in., and a roughness width not in excess of 0.008 in., as described further in Chap. XVII.

Bill of material: When the final engineering or manufacturing drawing of a device is finished, a bill of material is prepared. It usually is summarized on an assembly drawing, although the detailed drawing of each part indicates material for that part. This bill lists the number and names of all parts as numbered on the assembly drawing, the quantity of each unit required in the assembly, as well as the type, fabricated form, and amount of material as in Table 4. The weights of the rough stock and finished part are sometimes added for convenience. This is used in estimating cost and purchasing.

Routings: The next step in manufacture is to prepare routings for each part as called for under 5, Table 1. Each routing shows all operations on a piece, arranged in sequence. The specific types of machines and tools are listed for each operation, together with all operating conditions, size of cut, cutting speeds, and feeds which represent the best practice. From these data production rates are set, and the number of machines determined for each operation. Special measuring devices for inspection and manufacturing accessories also are listed by numbers which relate to the part number, operation, and type of tool (see Table 5).

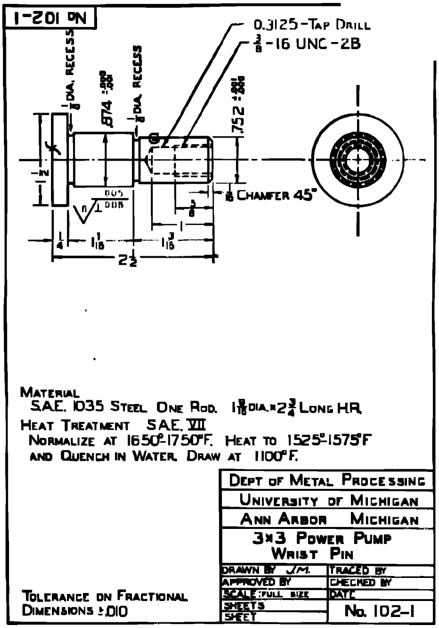


FIG. 5. A Manufacturing Drawing of a Component Part with Tolerances and Information for Complete Processing.

The boundary lines are 7 in. by 10 in., and then the sheet is trimmed to $8\frac{1}{2}$ in. by 11 in., with a 1-in. margin on the left. Larger sizes are trimmed to multiples of $8\frac{1}{2}$ by 11. The title block is $3\frac{1}{2}$ in. by $2\frac{1}{2}$ in. Surface quality is indicated as *f* (finish in no definite manner), *G* (grind but indefinite), and 8 (micro-inches r.m.s. obtained by grinding, lapping, etc.).

The various operations are governed by the type of equipment already available or to be purchased, and by the fabricated form of the material for the part. There often are several ways in which a part may be made, Fig. 1. The most efficient manufacturing method under existing conditions should be selected.

The main factor in determining the method is usually one of cost and convenience with relation to the plant and available equipment. The list of operations and equipment, based on the final manufacturing drawings, as summarized on the routing sheet, serves as a guide in laying out the equipment to provide the most economical flow of material through the plant. This design and routing should be as final as humanly possible before material is ordered and production is started.

This final form, however, cannot remain unchanged for long. Conditions are ever-changing and must be met by the engineers. Great

TABLE 4. A BILL OF MATERIAL

Illustrating the use of various types of materials. Reference should be made to the SAE and ASTM Handbooks.

Part			Material	
Number	Name	Number Required	Type	Form
1	Oil-filter shell	1	SAE 1010 steel	Sheets, 14 gage
2	Refrigerator condensor	1	Stainless steel, 18–8	Sheets, 20 gage
3	Camshaft	1	SAE 1020 steel, carburized	Die forging
4	Crankshaft	1	SAE 1045 steel, heat treated	Die forging
5	Connecting rods	2	SAE X3140 steel	Die forging
6	Airplane propeller shaft	1	SAE 4140 steel	Die forging
7	5/8 Hex head screw	36	SAE X1113 steel	Cold-finished bar
8	1/2-in. Filister head screw	24	SAE X1115 steel	Cold-finished bar (upset and cased)
9	Universal joint fork	2	SAE X1340 steel	Upset forging (oil hardening)
10	Large-speed reduction gear	1	SAE 2315 steel	Die forging (carburized and oil hardened)
11	Connecting-rod bolts	4	SAE 3130 steel	Annealed bars
12	Ball-bearing race	4	SAE 52100 steel	Seamless tubing
13	Coil spring	4	SAE 6150 steel	Cold-finished bar
14	Vacuum-cleaner body	1	SAE 305 Al-Si alloy	Die casting
15	Piston, automobile	8	SAE 34 Al-Cu alloy	Sand or permanent mold casting
16	Knob for automobile cowl	6	Cellulose acetate	Die molded
17	Truck differential housing	1	Malleable iron, ASTM A47–33	Sand casting
18	Phosphorus-bronze bushing	4	SAE 64 Cu-Sn-Pb alloy	Casting
19	Cylinder, engine	1	SAE 111 (200 B) cast iron	Sand casting
20	Truck-wheel hub	2	Carbon steel, ASTM A27–24	Sand casting

sums of money are constantly expended in large plants to introduce new materials, new fabricated forms, or new manufacturing equipment to effect economies and promote sales. Small savings on each part manufactured in quantities yield appreciable profits.

TABLE 5. AN ILLUSTRATIVE ROUTING OF THE GEAR SHOWN IN FIG. XI-20

For the production of 20 spur gears, a wood pattern and about 22 gray-iron castings are required.

Name of Product	No.	Name of Component Part	Material	Part No.
Spur gears	20	Spur gear, 58 teeth of 8DP 14½ deg pressure angle	Permanent mold casting of gray iron	

No.	Operation	Machine tool	Cutting tool material, size and type	Cutting speed rpm and fpm	Feed, in. (decimal)	Depth of cut, in. (decimal)	Chuck, jig, fixture, vise, clamp, etc.	Measuring instruments, gages, layout tools, etc.	Time, min.
	Name	Manufacturer and type of machine tool							
1	Machine blank	Warner and Swasey 2A universal turret lathe							
A	Roughing cuts	Turret face 1		34.5			Chuck, 3-jaw Expanding universal		
	(a) Core drill	" " "	1⅛ h.s.s. 3 fluted drill	10.4	0.030		"		
	(b) Face hub	" " "	⅜ × ⅝ × 3 h.s.s. bit	18.1	0.030		"		
	(c) Rough-turn O.D.	" " "	½ × 1 × 3½ Stellite bit	70.0	0.030	0.100	"		
	(d) Rough straddle-face rim	Rear cross slide	⅜ × ⅜ × 3 Stellite bit	70.0	0.025	0.100	"		2.30
B	Finishing cuts	Turret face 3		50.6			"		
	(a) Bore	" " "	5/16 × 5/16 × 2½ h.s.s. bit	16.4	0.025	0.055	"	Inside calipers and micrometers	
	(b) Finish-turn O.D.	" " "	½ × 1 × 3½ Stellite bit	100.0	0.025	0.025	"	Adjustable limit snap gage	

	(c) Finish straddle face rim	Front cross slide	⅜ × ⅜ × 3 Stellite bit	100.0	0.025	0.025	"	"	1.60
C	Finish hole	Turret face 6		120.0			"		
	(a) Ream	" " "	1¼ h.s.s. fluted (floating)	39.4	0.032		"	Limit plug gage	0.60
	(b) Break edges		12-in. bastard file	236.0					0.10
2	Broach keyway	American horizontal screwpull broach	¼ h.s.s. 50-tooth broach	4.5	0.0025 in. chip per tooth		Mandrel fixture	Limit plug gage	1.02
3	Back-face hub	Snyder upright 20-in. drill press	⅜ × ⅞ h.s.s. bit	30.0	0.0027		"		0.62
4	Mill teeth	Brown and Sharpe No. 2 plain horizontal milling machine	No. 2. 8DP, 10-tooth 3-in.-O.D.-cutter h.s.s.	70.0	0.020	0.2696	Mandrel and dividing head*	Gear-tooth vernier calipers	21.20
5	Final inspection, 10%	Workbench						Repetition of above gages plus gear-tooth inspection device	3.20
								Total per gear	30.64

* Indexing 20 spaces on 29-hole circle with 3 gears on mandrel.

Prints of those parts made from castings must be sent to the pattern shop where patterns are designed, constructed, and delivered to the foundry. Prints of parts made in presses or by forging or upsetting are sent to the die-design section where the designs are executed by specialists. The dies then are constructed in the toolroom and die shop. Prints of parts requiring machining operations, with copies of routings of the part, are sent to the tool-design division where jigs, fixtures, and inspection gages are designed. Many times these jobs are turned over to specialized outside plants to be designed and constructed.

Again in the construction of these dies, jigs, gages, etc., standard materials are available to meet various requirements. Each plant usually standardizes materials and methods as a result of years of experience or recommendations from reputable suppliers. The degree of elaboration of any design should depend upon the purpose for which it is intended. A large expenditure is justified for large production. Frequently, however, special tools are required only because the job cannot be accomplished satisfactorily otherwise.

Time Study: The time required for each operation is determined from the production data summarized on the routing sheet. The time for each operation may be estimated by the production supervisors, computed from speeds and feeds, or determined by a time and motion study. Equipment in the form of stands, conveyors, etc., should be provided where needed so as to expedite the operation and reduce fatigue as much as possible. From these production rates, the number of machine tools required for each operation is determined.

A **standard time** may be defined as the time required for an average worker to accomplish a task when working steadily without overexertion. **Allowances** are included for any regularly occurring interruptions such as for grinding or adjusting tools, preparation, personal delays, fatigue, inspection, and delays of various sorts. The rate of production set should anticipate a fair day's work. It is used as a basis of wage payment or operation costs. Frequently a premium or bonus is paid the worker for all production over that set as the standard.

In determining a standard time, the operation or task is first divided into its natural divisions or elements (see Table 6). Care should be taken to separate the machine or labor elements in these divisions, as it is on the labor time that allowances for personal delays, fatigue, chance for speeding up production, etc., are actually based. Labor elements, such as tool grinding and setting up machines, require individual studies and may or may not be included in the operation and allowed for in the standard time.

TABLE 6. SAMPLE TIME-STUDY SHEET

Operator's Name Harry Lewis **Job No.** 30 **Date** Aug. 3, 1950
Skill B **Effort** A **Observer** Jones
Machine Tool No. 33 **Manufacturer** R. K. LeBlond rapid production lathe with turret tool post
Component Part Movable jaw **Material** Die forging of S.A.E. 1030 steel
Operation Drill and ream through hole 0.5625 in. dia. x 7.5 in. long
Remarks Universal chuck had formed jaws. Emulsion of 1:20 supplied by attendant

Elements of Operation		Cutting Tools				
No.	Name	Name	Speed		Feed	Depth of Cut in Inches
			R P M	F P M	I P R	
1	Pick up and chuck piece					
2	Start the spindle					
3	Advance the drill in turret by hand					
4	Engage power feed and drill	35/64 h.s.s. twist drill	407	60	0.007	1 in. travel
5	Withdraw drill and index turret					
6	Advance reamer and ream, hand feed	9/16 h.s.s. fluted reamer	200	30	hand	1 in. travel
7	Withdraw reamer, index turret, and stop spindle					
8	Remove piece from chuck					

Time-Study Observations in Hundredths of a Minute

Element No.	1		2		3		4		5		6		7		8		9		10		Minimum Time	Average Time
	CT	IT	CT	IT	CT	IT	CT	IT	CT	IT	CT	IT	CT	IT	CT	IT	CT	IT	CT	IT		
1	7	7	8	8	5	5		7		5	12*	12	3*	3		7	8	8		6	5	5.6
2	12	5	13	5	12	7		5		5	18	6	12	9		7	15	7		8	5	6.4
3	18	6	22	9	20	8		7		8	22	4*	22	5		8	22	7		7	5	7.2
4	35	17	37	15	40	20		15		17	43	21	37	15		18	38	16		17	15	17.1
5	47	12	48	11	53	13		13		12	53	10	43	6*		13	52	14		12	10	12.2
6	62	15	67	19	70	17		17		15	73	20	59	16		17	65	13*		16	15	17.0
7	82	20	85	18	87	17		18		20	93	20	77	18		20	83	18		19	17	18.8
8	88	8	93	8	93	6		7		8	101	8	88	11		10	90	7		8	6	8.1

Note: CT is continuous time; IT is individual time. **Total in Minutes** 0.78 0.924

Allowances: Fatigue and personal 10.0%
Grinding tools (20 min. in 8 hr.) 4.2%
Total 14.2% 0.131

Total allowable or standard time 1.055
Pieces per hour 56.9
Hours per piece 0.0176

A simple and commonly used method of determining a standard time is illustrated by the observation sheet, Table 6. The fourth element alone is purely machine time, the balance depending upon the operator (labor). The time-study man must then seriously consider the type and effort of the operator — is he skilled or unskilled, fast, slow, average, stable, or variable? This time study shows ten sets of readings; in practice, more are advantageous, taken at different times during the day. Some of these times are continuous; i.e., a stop watch graduated in hundredths of a minute is started at the beginning of one element and allowed to run until that same point of the cycle is reached again, but readings are taken and tabulated at the beginning of each element. The lapsed time of each element is then determined by subtraction. The fourth and eighth readings are individual times, the watch being started at the beginning and stopped at the completion of the element so that lapsed time is obtained directly. The figures marked by asterisks are thrown out since they are too high or too low and are not believed to be representative. After the ten readings have been completed, the minimum time of each element is selected and tabulated in the right-hand column for guidance. The average time for each element is also determined and tabulated. These averages are totaled. The differences between the selected minimum time and the average time for each element should not be excessive.

The sum of the average time and allowances is then expressed as the standard time in pieces per hour and hours per piece.

The Machine Shop

The object of the machine shop is to machine parts to predetermined standards and possibly assemble the parts into sub- or final assemblies for shipment. All metal devices or machines are manufactured on a **machine tool.** *These are power-driven machines designed to hold a part to be machined and drive a cutting tool so as to cut chips from the material to the required extent.* Machine tools include lathes, planers, shapers, drilling machines, milling machines, saws, grinders, broaches, presses, etc., of a wide variety of types and sizes.

Cutting tools comprise single-point tools for turning, boring, shaping, and planing, milling cutters, drills, reamers, taps, dies, broaches, saws, and abrasives, each of a great variety of types, materials and sizes. The cutting tool is named for the machine tool or **process** by which chips are removed.

In the following chapters, the machine tools and cutters of the various processes and functions are treated separately more in detail.

There are hundreds of thousands of machine shops throughout this country. Some of these are large and scientifically operated; many are small with complete control in the hands of the machinist-owner.

Most of the larger shops were started by a skilled machinist providing himself with a few machine tools and cutters to do miscellaneous or jobbing machine work, as described below.

Such a small **job shop** usually contains an engine lathe, an upright drill press, a knee-type milling machine, a power hack saw, a shaper, and a two-wheel floor-type tool grinder. A portable electric-power drill and grinder are commonly included. Cutters for these machine tools consist of forged tools or tool-bit holders for the lathe and shaper; drills, reamers, counterbores, countersinks, etc., for the drill press; offset boring heads, end mills, milling cutters, etc., for the milling machine; saw blades for the saw; and abrasive wheels for the grinder. Chucks, vises, and clamps are provided to hold the work in the various machines. Many added accessories, such as hammers, chisels, files, and measuring tools, are needed.

If the work increases, a second engine lathe will be necessary; or if large parts are to be machined, a radial drill press and planer are added. A cylindrical, internal, or surface grinder may be necessary to finish some of the work to the size and surface desired.

The owner of a growing shop finds that he can no longer do machine work, as he is called upon to solicit work, devise machining methods, inspect and deliver the finished work, hire additional labor, set rates, keep manufacturing costs, bill accounts, pay his workmen, purchase raw materials and supplies, etc. Additional specialization is necessary. One of the best machinists is asked to act as a foreman in charge of production. A stenographer and accountant are necessary in the office. Another good machinist is assigned the duties of draftsman to prepare drawings of parts to be machined. A timekeeper, a cost clerk, an inspector, a maintenance and repairman, a purchasing agent, and many others, more or less specialized, are needed to take care of the constantly increasing volume of business. The organization thus becomes one of **specialists,** as indicated in Fig. 2.

The work so far done in this shop was of the **job-shop type,** in which only small quantities of any single piece had been produced. The equipment, therefore, was such that, with the use of a variety of attachments, many different types of work or jobs could be done on the machines with only a slight modification of the setup by the machinist.

Large manufacturers began sending in work which called for the production of relatively large numbers of each piece. This introduced new problems. The machining of the parts in small or even large lots may be done by equipping the job-shop machines with jigs or fixtures to hold the work while it is being machined, and may at the same time make possible substantial savings in loading and unloading time. The introduction of jigs and fixtures and special tools calls for a man, commonly known as a tool engineer, to design tools and jigs or fixtures for each operation.

Semiproduction machine tools also may be purchased for machining lots of moderate quantities. These are purposely constructed to be adapted readily to a certain class of work, and they may be used in the job shop for small lots or for limited-production work. A variety of tools and toolholders is included in the standard equipment of the semiproduction machines, such as the turret lathe and screw machine, and these accessories are so constructed that relatively little time is required to change the tooling setup from one lot-production job to another.

After the shop has operated successfully for some time on the job-shop and semiproduction basis, orders may be received to produce various parts in large quantities, that is, **mass production. Production machine tools,** such as the centerless grinder, automatic gear cutter, automatic screw machine, semiautomatic turning machine, and semiautomatic multiple-spindle drilling machine, are purchased to do the work. These machines are an outgrowth of the standard job-shop machine simplified to do a limited range of work when provided with special-purpose jigs and fixtures, or they are designed to machine a given part, usually employing multiple tools so that a number of tools work simultaneously, or so that a number of operations are performed automatically and successively on the piece. This type of machine usually has many automatic features. After loading the part, the operator starts the machine on its cycle which is continued automatically until the machining is finished, when it is stopped. Many automatic machines, such as the automatic screw machine, produce parts continuously without the attention of an operator after being loaded with bar stock. One operator often attends several machines. The setup of these machines is so specialized and complex that several hours or even days may be required to accomplish it. Often special formed tools are made for the given job.

Very large production has stimulated builders to design and construct machine tools for a **single purpose,** such as turning pistons, boring cylinders, drilling cylinder blocks, and gear cutting, which operate for months or years on one setup. This type of machine is an important factor contributing to the extremely low manufacturing cost found in such plants as those of the automotive industry.

The production superintendent in charge of the machine shop, tool supervisor, and plant engineer work closely together. They should understand thoroughly such subjects as routings; material handling and control; power transmission; standardization of materials, equipment, and labor; production scheduling; time and motion study; wage payment; and accounting and costs, because of the necessity of complete cooperation in reducing and controlling costs. The production superintendent is in charge of all foremen and direct labor engaged in the production of the product and is responsible for maintaining the rates of production as scheduled.

Plant Layout

As soon as the method of manufacture is agreed upon as exemplified by the routing, the plant is prepared for manufacture. Machine tools, as determined from the routing, must be provided and arranged; and all accessories, including conveyors, designed and constructed. It is a good practice to cut scale models from heavy paper at ¼ in. per ft and lay them out on the floor plan as illustrated in Fig. 6. Wood or die-cast models are available so that height of equipment may also be considered. With their help, overhead conveyors, pipes, and structural members of the building can be accommodated. A final layout for mass production is shown in Fig. 7.

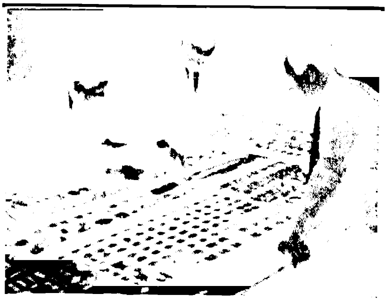
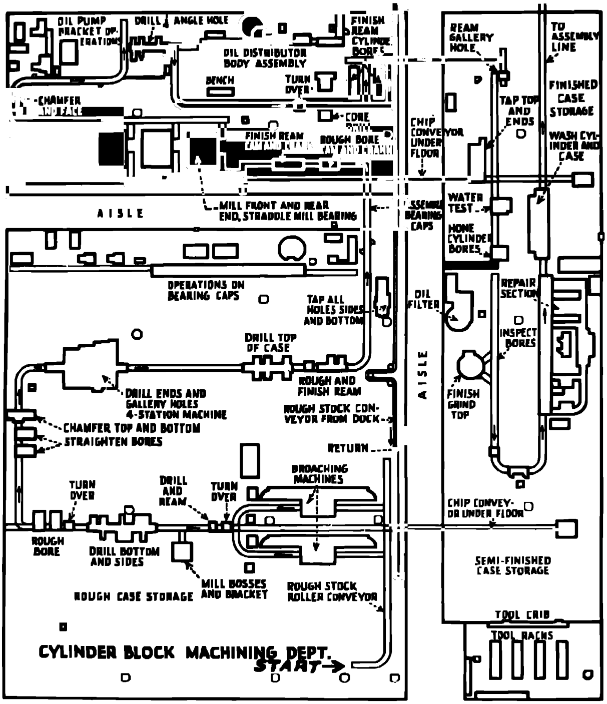


FIG. 6. Preliminary Plant Layout Using Card Forms Cut to Scale to Represent Machines.

In small job shops the work is carried from one machine to another by one **all-round machinist,** for the successive operations. The machine tools are arranged in a convenient way under a general foreman. Work in small and large lots has one operation done by one **specialized machinist,** as in milling, on a machine tool of a type grouped under one foreman specializing in that line of work. The lot in tote boxes, on racks, or on trucks is then delivered to a machine of another type, such as grinding, located in another group under a specialized foreman, where the next operation will be done on all pieces by a grinding machinist, etc.

In mass production a foreman may be in charge of a department covering the complete manufacture of a given part. There are, for instance, crankshaft departments in which one man is in charge of the production of crankshafts. In this case, machines of a wide variety are grouped together and often arranged so that the part passes from one machine to the next progressively through all the operations from rough stock to the finished part, as listed on the routing. This is called **progressive line machining** and the machinists are **machine operators** trained only in the operation of that one machine.



From American Machinist.

FIG. 7. A Final Plant Layout for Progressive Line Machining an Automotive Cylinder Block.

QUESTIONS

1. What are the four principal factors involved in metal cutting?
2. Explain the Society of Automotive Engineers' symbols for designating steels.
3. What are the SAE and AISI symbols for medium-carbon steel? Define them.
4. Of what materials are cutting tools made?
5. List and describe each step of a manufacturing design.
6. What is a job shop?

7. What are some of the machine tools generally found in job shops?
8. Of what does the cost of manufacture in a job shop consist?
9. What are semiproduction machines? Name several.
10. What is meant by mass production?
11. What are some of the tools used in mass production?
12. Explain the three types of machine shops, based on production methods.
13. In what form is material fabricated for use?
14. Explain the relation of the machine shop to other departments.
15. What are the duties of the tool engineer?
16. What are some of the features embodied in the final design of a part which are helpful in production?
17. What is meant by the manufacture of interchangeable parts? Selective assembly?
18. Explain the relationship between a routing and a plant layout.
19. Explain the meaning of the terms: fit, allowance, tolerance, and limit.
20. A liquid is to be marked in 12-oz packages. Explain the advantages and disadvantages of using tinned-steel cans, glass bottles, paper cartons, or plastic cups.
21. Compare the properties and use of a small part, such as a cup, if made from powdered aluminum metal, an aluminum stamping, a molded plastic, or machined from bar stock.
22. Name the advantages of the Unified Screw Threads, first as to use and second as to strength.
23. Compare the relative merits of (*a*) a steel or aluminum stamping; (*b*) a gray-iron casting and steel forging; (*c*) a zinc die casting and a molded plastic; (*d*) a stainless steel part machined from bar stock and a pressed and sintered bronze powder; (*e*) a copper-tin bronze bushing machined from cast bars and a porous Oillite or graphitic bushing made by powder metallurgy; and (*f*) a small flange part made by machining a casting or by welding or brazing two steel stampings together.

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CHAPTER II

LATHES

THE ENGINE LATHE AND ITS DEVELOPMENT

A lathe is a machine tool which holds a piece of material to be turned to a cylindrical section between two rigid supports called centers, or in some device, such as a faceplate or chuck, attached to the overhanging end or nose of the spindle. The spindle carrying the work or material to be cut is made to rotate while a cutting tool, fixed in a tool post supported on a carriage which slides over the bed, is brought into contact.

Modern cutting tools are of such excellence that the tendency in machine-tool design is to provide a combination of high ranges of speeds and feeds accompanied by great rigidity and accuracy. This has led to the wide use of antifriction bearings; alloy steel gears, hardened, lapped, or ground; helical or herringbone gears; and almost completely automatic lubrication.

CLASSIFICATION OF LATHES

It is difficult to classify definitely all existing lathes now on the market, because of the wide variety of types, sizes, and builders. Many are designed for general use and others for a specific purpose. They may be classified in accordance with their features of design or construction and the purpose for which they are intended. From the design point of view there are:

1. **Bench** lathes, Figs. 1 and 2, and **floor-type** lathes, Fig. 3.
2. **Speed** lathes in which the tool is actuated by hand, and **engine** lathes in which the tool is fed by power through a feed rod or lead screw, or by hydraulic pressure.
3. **Solid bed** lathes, Fig. 2, and **built-up bed** lathes. Solid bed lathes may have constant swing between the headstock and tailstock, or have a permanent gap in the bed between the headstock and the ways on which the carriage slides. This gap permits a workpiece of a larger diameter to be swung over the bed below the spindle nose than could be swung over the ways. The built-up bed may have a sliding upper part which may be moved away from the headstock to provide a gap between the end of the sliding bed and the headstock, or a section of the bed below the overhanging spindle may be removed to provide the gap.
4. **Step-cone-pulley** drive, Fig. 4, or **geared head**, Figs. 6 and 8.
5. **Horizontal-spindle** lathes, Fig. 2, and **vertical-spindle** lathes, as represented by the vertical turret lathe, Fig. XI-7, and the vertical boring mill, Fig. 19.

Speed lathes are those in which the tool is actuated by hand. The lathe usually consists of a bed on which are mounted a headstock and tailstock to support the work and a carriage or adjustable slide to support the tool. The speed lathe is similar to the engine lathe, Fig. 1, except that it has no power feed to the carriage. The tool may be supported on a T rest, or held in a tool post which is supported on the cross slide and carriage. The work is held between the centers of the head- and tailstock or attached to the chuck or faceplate on the headstock. Such lathes are designed for wood turning, lapping, polishing, light metal cutting, or even spinning sheet metal.

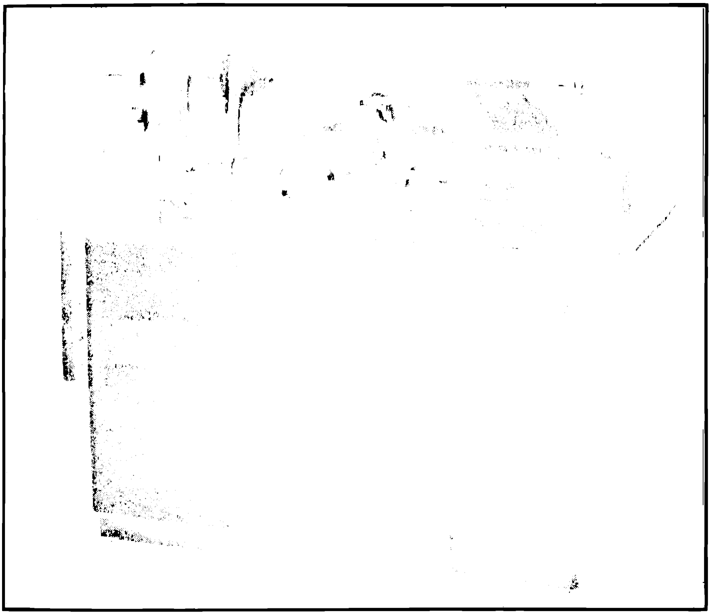
Courtesy South Bend Lathe Works.

FIG. 1. The 9-in. Swing, 16 in. between Centers (22, 28, and 34 in. Available) South Bend Model A Bench Lathe.

Cabinet-mounted $\frac{1}{4}$-hp a-c motor mounted at the rear of the headstock drives to the jack shaft, having a 3-step-cone pulley which drives by flat belt to the spindle. With back gears six speeds are available from 79 to 1,270 or 41 to 658. With $\frac{1}{2}$-hp motor and 2-speed jack shaft, 12 speeds are available. The lathe equipped with quick-change gears will cut threads of 48 pitches from 4 to 224 per inch. Power longitudinal feeds from 0.0015 in. to 0.0853 in. are available with cross feeds from 0.0004 to 0.0252 in. Toolholder shank of $\frac{3}{8} \times \frac{13}{16}$ for $\frac{1}{4}$-in. sq. bit is used. This lathe is in the low-price class, approximately $250.

The **engine lathe,** Fig. 1, is the common power-driven lathe adapted to do a variety of work; the **production engine lathe** which is rigidly and simply constructed for production work; and the **toolroom lathe** which is the engine lathe provided with extra attachments and refinements for miscellaneous accurate toolroom work.

The carriage is power driven by a feed rod or lead screw in turn driven from the spindle, as shown in Fig. 10. The carriage may be fed longitudinally and the cross slide transversely on most engine lathes by driving the feed rod from the spindle through a short belt on the step-cone pulleys, Figs. 3 and 17, or through change gears connecting the step-cone-pulley shafts, also shown in Fig. 3, or through quick-change gears built into the machine, as shown in Figs. 6 and 10. Two manufacturers use a lead screw keywayed its whole length to serve as lead screw and feed rod combined, Figs. 1 and 4. For accurate thread cutting, the non-rotating half nuts on the carriage apron engage the rotating lead screw and drive the tool positively, but for

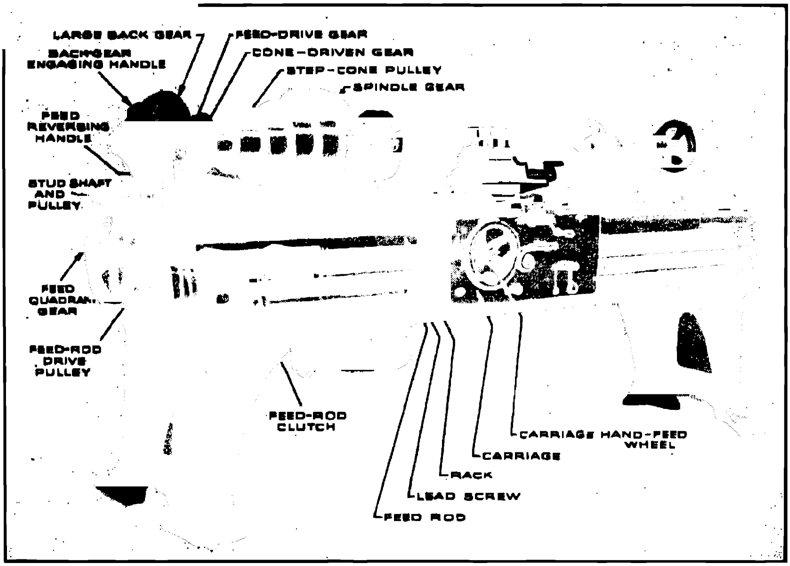


Courtesy Hardinge Bros., Inc.

Fig. 2. The Hardinge Model HL High-Speed Precision Toolroom Bench Lathe and Cabinet.

The motor for driving the spindle is mounted in the cabinet leg under the headstock. Infinitely variable speeds are available to the spindle. The tailstock cabinet is provided with shelves for holding extra chucks, centers, tool posts, steady and follow rests, etc. The machine has a 1-in. collet capacity, a 5¾-in. swing over the cross slide, and 18-in. center distance. The independent variable-speed motor on the carriage provides a drive for infinitely variable carriage and cross-slide feeds. The control box is mounted on the right end of the bed. This drive reserves the gear box and lead screw for precision threading 27 threads from 11 to 108 per inch. One-piece hardened steel ways are used.

general work, such as turning and boring, the keywayed shaft drives the carriage through friction clutches in the apron (see Figs. 13 and 14). Most other lathes, Figs. 2, 6, 10, and 16, have a lead screw for accurate thread cutting, and an independently driven keywayed feed rod to provide the frictional feeds to the carriage for general cutting.



Courtesy The Flather Co.

FIG. 3. Flather 21-in. Swing Screw-Cutting Lathe (before 1898).

Ten spindle speeds available from the five-step-cone pulley and single back gear. The spindle drives the stud shaft carrying the small three-step pulley. This stud shaft may drive the feed rod by belt to the larger three-step pulley for general turning, or drive the lead screw by standard change gears stored on the swinging table underneath the bed, through the large idler gear, when positive feeds are required, such as for thread cutting. The lead screw (top) furnishes a positive drive to the carriage, of threads per inch while the feed rod drives through a friction clutch, a train of gears in the carriage apron, which engages the rack shown underneath the upper edge of the bed to give the tool feed in inches per revolution of the spindle.

The lead screw drives the carriage by engaging two half nuts attached to the carriage. Two clutches are provided to engage the feed rod: one to drive the carriage longitudinally by means of the carriage rack gear, Fig. 14, which engages the rack on the bed, Fig. 12, and the second to drive the cross-feed gear which rotates the cross-slide feed screw.

Engine lathes may be classified into four principal groups in accordance with the method of furnishing power to the work (speeds) and tool (feeds), as follows:

(*a*) Step-cone-pulley drive with single or double back gears to provide various speeds of the work, and loose change gears to provide various accurate feeds for the carriage and cross slide as illustrated in Fig. 3. In such old machines, for general cutting, power feed is transmitted by belt from the stud to the feed-shaft pulleys.

(*b*) Step-cone-pulley drive as in (*a*) to furnish speeds, and semi- or quick-change gears to provide feeds. Semiquick-change gears, Fig. 4, provide only a limited range of feeds from the gearbox for each setup of loose gears. Extra gears are needed for additional feeds. Figure 2 shows fully built-in quick-change gears controlled by two levers.

(*c*) Single-pulley, constant-speed, or geared-head drive for selective speeds and quick-change gears for feeds, Figs. 6 and 10.

(*d*) Class (*c*) arranged for constant-speed motor drive.

(*e*) Class (*c*) arranged for limited adjustable-speed direct-current motor drive.

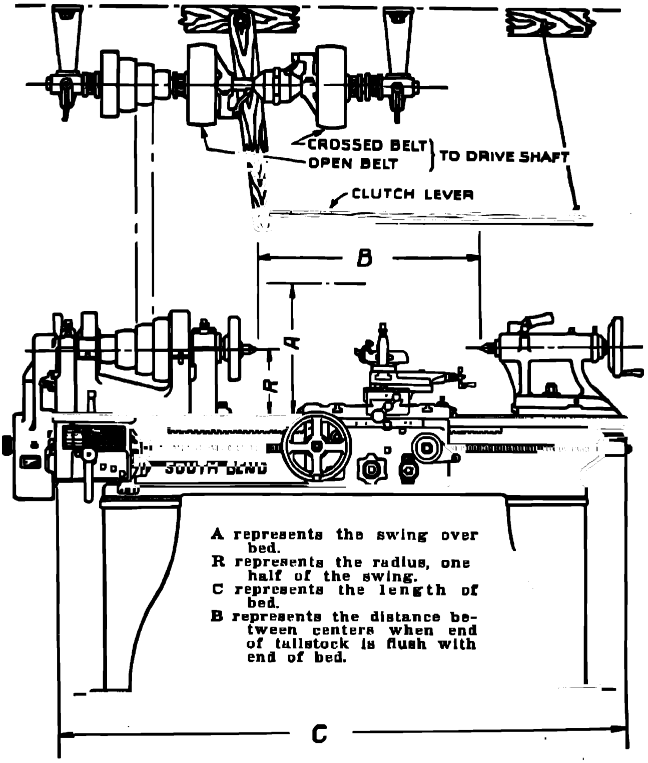
(*f*) Class (*c*) arranged for any speed in infinitesimal steps over a wide range, as with the Ward-Leonard drive consisting of a motor generator with field exciter to control the field and rotor voltage of the driving d-c motor, Fig. 11.

(*g*) (Same as (*f*), except the d-c motor voltage is controlled by transformers and by electronic tubes, etc., Fig. 18, instead of the motor generator, Fig. 17.

(*h*) Infinitesimal-speed-variation drive directly to the spindle, Fig 18.

For the class (*a*) lathes, a **countershaft** is necessary, Fig. 4, which carries at least two clutch pulleys and a step-cone pulley matching that on the lathe. The two clutch pulleys are driven from a main drive shaft, one with an open belt for forward speeds, and the other with a crossed belt for reverse speeds. Where reverse speeds are not needed, the second clutch pulley can be driven by an open belt from a larger pulley on the main drive shaft, thereby doubling the range of speeds of the machine. With the clutch of the open-belt pulley on the countershaft engaged, various spindle speeds are obtained by shifting the belt from one step to another. With the **back gears,** Fig. 5, disengaged and the cone pulley attached to the large gear on the spindle by the lockpin, the cone pulley drives the spindle directly. With back gears engaged and the lockpin withdrawn from the cone pulley, the spindle is driven by the cone pulley, not directly but through the back gears, so that an equal number but slower range of spindle speeds may be obtained. The cone pulley drives the 28-tooth gear, which in turn drives the 56-tooth gear and the backshaft. The 24-tooth gear drives the 64-tooth gear, which is keyed to the spindle. In some more recent designs to make a self-contained unit, the countershaft and driving motor are mounted below the spindle in the cabinet leg as in Fig. 2. Multiple- or adjustable-speed motors may be used in such cases.

The single-pulley drive or geared-head lathe, class (*c*), is so arranged that eight or more spindle speeds are obtained readily through the various speed gears. This type of machine is equipped with quick-change gears for power feed to the carriage. Geared-head lathes may be driven from a line shaft by belt or arranged for direct motor drive, class (*d*). The motor may be mounted in the cabinet leg under the spindle, Fig. 10, on the rear of the leg, Fig. 11, or on the top of the head, using a short flat belt, a multiple V belt, a silent chain, or direct gear drive. A flanged motor mounting is shown in Fig. 16, in which the motor shaft is coupled directly to the drive shaft. Where speed increments smaller than those permitted by speed gears or steps on the cone pulley are required, the power may be transmitted through



A represents the swing over bed.
R represents the radius, one half of the swing.
C represents the length of bed.
B represents the distance between centers when end of tailstock is flush with end of bed.

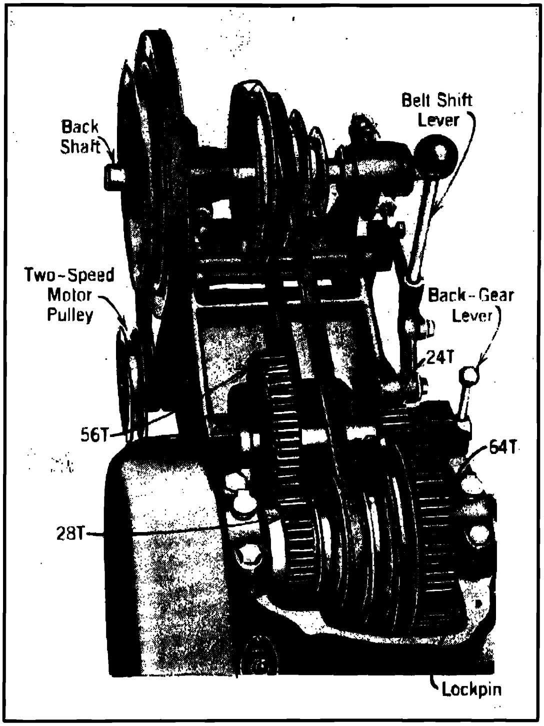
Courtesy South Bend Lathe Works.

FIG. 4. Line Diagram of the Countershaft Driven South Bend Engine Lathe; Size Is $A \times B$.

Showing methods of designating the size of lathes and the arrangement of the two-speed, or forward and reverse, countershaft driving to the four-step-cone pulley which is supplemented with back gears. The lead screw feeding the carriage is driven, for thread cutting and general work, through the quick-change gears. The lathe is started, reversed, or stopped by engaging the clutches on the countershaft, by the clutch lever.

variable-speed transmissions of the mechanical type, Fig. III-8, the hydraulic motor, or the d-c motor, Figs. 11, 17, and 18.

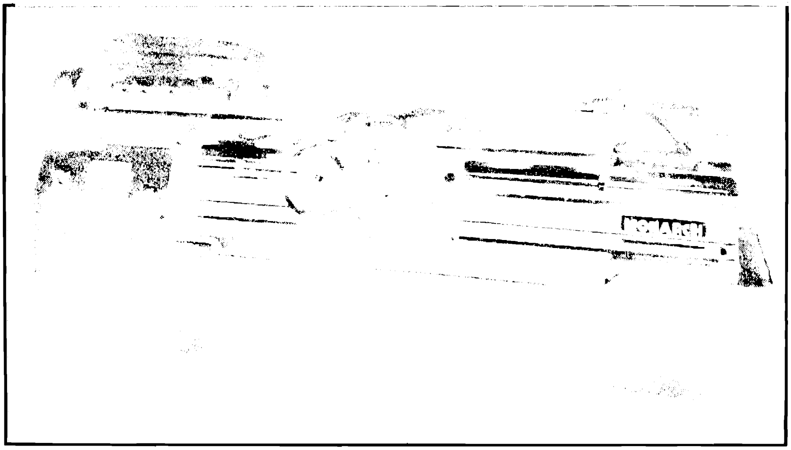
Vertical lathes require less floor space and add to the convenience of chucking heavy work on a horizontal table, the table itself serving as a chuck. A **vertical turret lathe,** Fig. XI-8, having a turret on a vertical ram and a four-way turret on a horizontal ram, is used for job-shop and small-lot production work. The vertical turning and **boring mill** having two rams, Fig. 19, is made in large sizes for turning, facing, and boring large castings and forgings. These machines are discussed further under turret lathes, Chap. XI.



Courtesy The Atlas Press Co.

FIG. 5. A Plan View, with Covers Removed, of the Driving Mechanism of the Atlas 10-in. Lathe Headstock, Showing the Spindle Pulley and Back Gears, the Backshaft, and the Two-Step Motor Pulley.

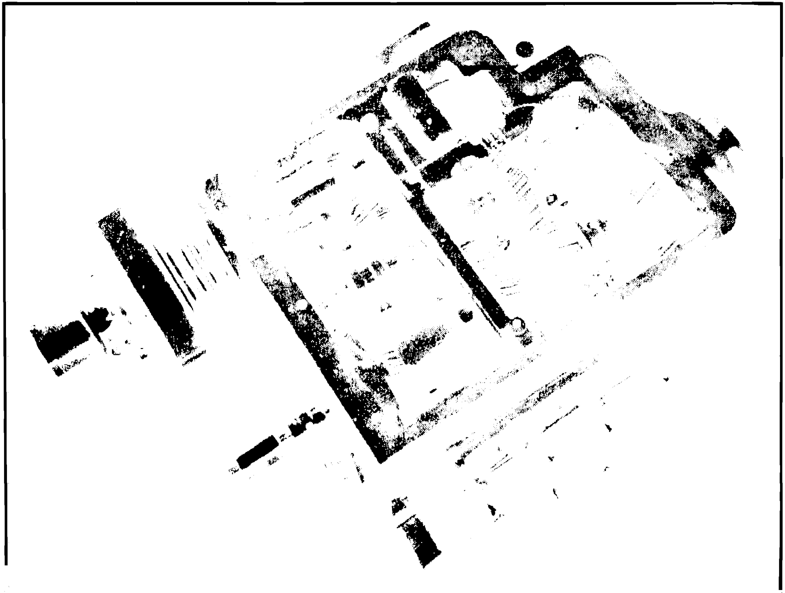
A four-step pulley and 32-T gear rotate freely as a unit on the spindle. With back gears in, 4 spindle speeds are available for each step of the motor pulley. With back gears out, 4 additional speeds are available, and with the two-diameter motor pulley, 16 speeds in all are available. When the back gears are engaged, the large 64-T gear which is keyed to the spindle is disconnected from the spindle pulley by the lockpin. When the back gears are disengaged, the lockpin engages the large gear with the spindle pulley for direct drive to the spindle. The back-gear ratio is $^{28}/_{56} \times {}^{24}/_{64} = {}^{3}/_{16}$.



Courtesy Monarch Machine Tool Co.

Fig. 6. The Series 60 Monarch Toolmakers Lathe Provided with Universal Relieving Attachment.

The universal joints in the drive provide smooth positive operation of the relief cam at all angular positions of the compound rest. This lathe is available in 14-, 16-, 18-, and 20-in. swings with any desired center distance.

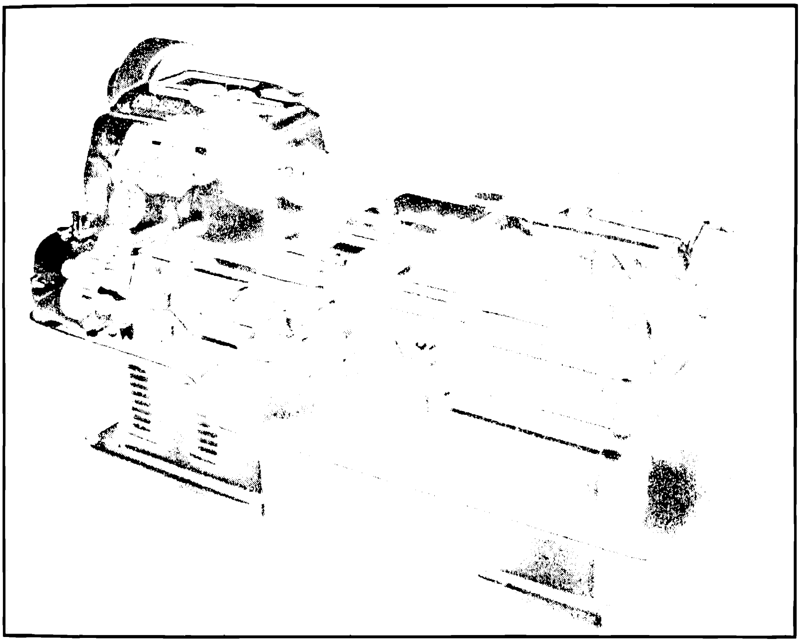


Courtesy Monarch Machine Tool Co.

Fig. 7. A Plan View of the Headstock of the Series 60 Monarch Engine Lathe with the Cover Removed.

Hardened and ground alloy steel shafts and helical gears are used. The spindle and intermediate shaft have center bearing supports. With gears in constant mesh, speed changes are made by sliding jaw clutches. Combined pump and splash lubrication to bearings and gears is provided.

There are many adaptations of the engine lathe for repetitive work or mass production, such as the **car-wheel** lathes, designed purposely for turning railroad car wheels, in which the tools operate from both ends of the lathe and the work is driven from the center; **crankshaft** lathes for turning various types of single- or multiple-throw crankshafts; **camshaft** lathes; **pulley** lathes; **turret** lathes; **toolslide** lathes; **automatic chucking** lathes; and **automatic screw machines,** discussed in following chapters. Electric, hydraulic, and pneumatic devices are also provided on engine lathes, so that master templates or components can be duplicated automatically.

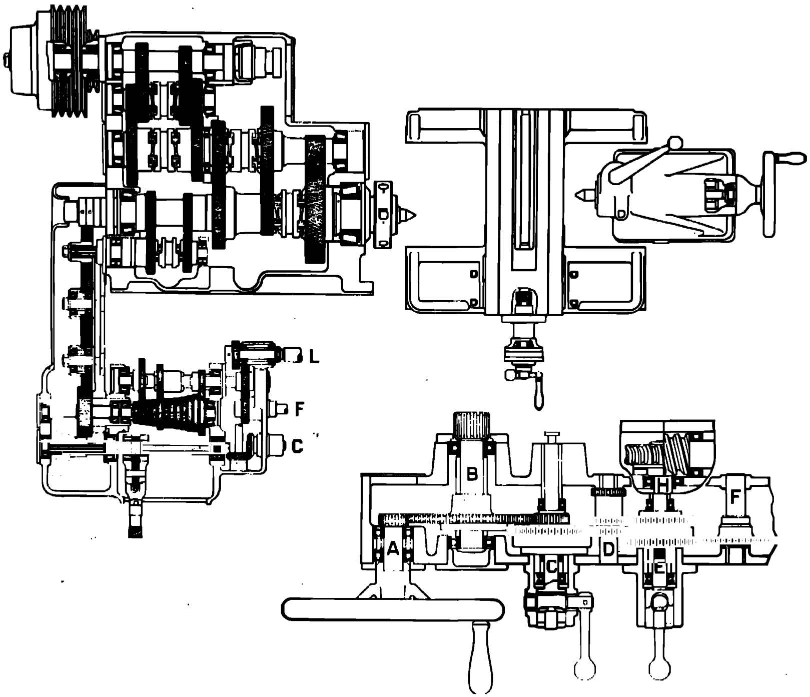


Courtesy Monarch Machine Tool Co.

FIG. 8. A Phantom View of the Model C Lathe, Showing All Hardened Members such as Shafts, Gears, Lead and Feed Screws, and Bearings.

THE SIZE OF A LATHE

The size of screw-cutting, engine, and toolroom lathes is designated usually by the swing and distance between centers. The swing is the nominal diameter in inches of work it will swing over the bed or wings of the carriage. The maximum swing is 2½ in. larger, as illustrated by *A* in Fig. 4. The distance between centers is the length of a piece which can be supported between centers with the tailstock flush with the end of the bed, as indicated by *B*. Sometimes the overall length, *C*, of the bed of the lathe is given, but lathes having the same length of bed may vary in center-to-center capacity. A 14-in. lathe has a nominal swing of 14 in. diam. over the bed ways, and it will swing a cylindrical bar about 30 in. long between centers, and 9 in. diam. over the carriage cross slide. Lathes are made in all sizes up to 72-in.-diam. swing by any center distance desired.



Courtesy Monarch Machine Tool Co.

FIG. 9. Line Diagram through the Monarch Type C Toolroom Lathe, Showing All Bearings, Gears, and Clutches to Drive the Spindle, Lead Screw, Feed Rod, Carriage, and Cross Slide.

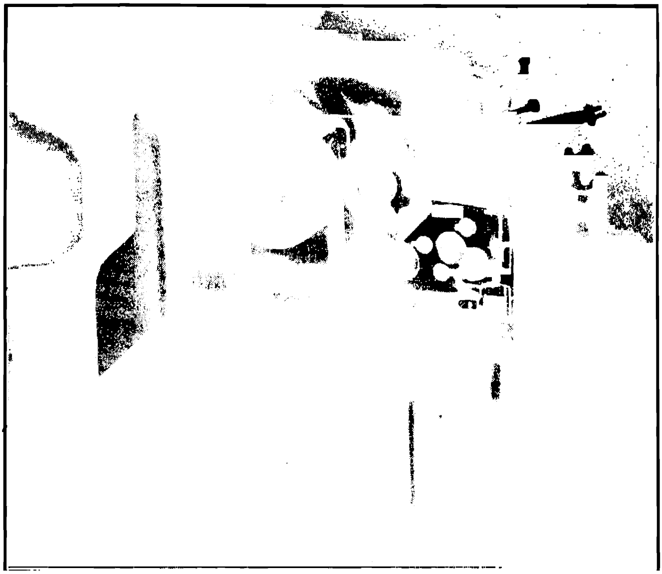
GEOMETRICAL PROGRESSION OF SPEEDS

It is general practice to vary the speeds of machine-tool drives in geometrical progression, each speed being obtained from the preceding one by multiplying by a constant called the constant ratio r, so that the several spindle speeds, revolutions per minute, are: b; br; br^2;

br^3; . . . ; $br^{n-1} = a$. The value of b is the lowest speed in the formula for geometrical progression, a is the highest, and n is the number of speeds; then

$$r = \sqrt[n-1]{a/b}$$

Most modern lathes are built with geared heads providing 8, 12, 16, or 24 speeds, with values of r of about 1.58, 1.36, 1.26, and 1.12, respectively. Levers are provided to shift clutches or gears. One shift may change from one speed to another, by the ratio r, or another may introduce the back gears (built into the gear drive) and change speeds by the back-gear ratio, such as r^4, r^8, r^{12}, to give the low series of speeds while direct drive gives the high series. The arrangement of gears, shafts, and clutches in the geared head of the Monarch lathe, series 60, is shown in Fig. 7.



Courtesy American Tool Works Co.

FIG. 10. An End View of the Pacemaker Lathe with the Door Open, in Which the Motor Mounted under the Headstock Drives to the Constant-Speed Driving Sheave by Multiple V-Belts.

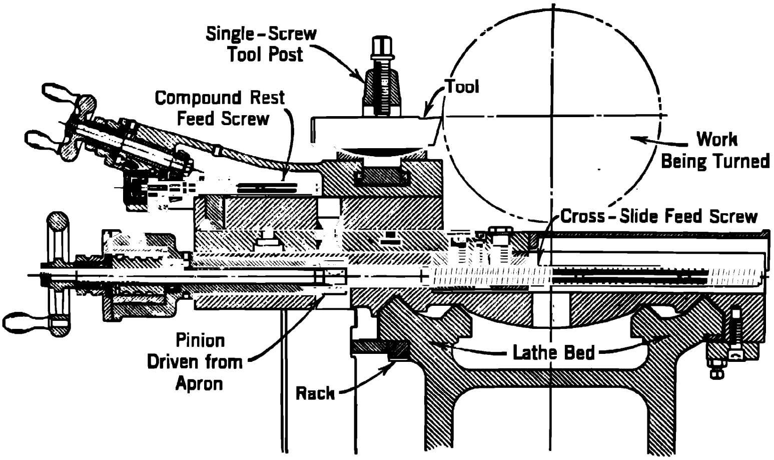
The driving clutch and brake are just back of the driving sheave. The spindle shown as tubular shaft is driven by the sliding clutches and gears in the headstock. The small gears drive from the spindle to the feed gearbox. The miter gears are part of the linkage controlled from the front of the lathe to operate the driving clutch to stop and start the spindle.

Feeds: Most screw-cutting lathes will cut many differently pitched screw threads, such as 36, ranging from 1½ to 80 per in. The feed rod

Courtesy American Tool Works Co.

FIG. 11. The Platform Mounting for Motors too Large for the Cabinet Leg.

The motor shown is for d-c current supplied from a motor generator, from a Ward Leonard motor generator and field exciter unit, or from the electronic control panel. The last two drives give a 100 to 1 speed variation in infinitesimal steps. The motor mounting base serves as a cutting-fluid tank; the fluid is circulated by the centrifugal pump driven by the small vertically mounted motor in the foreground.

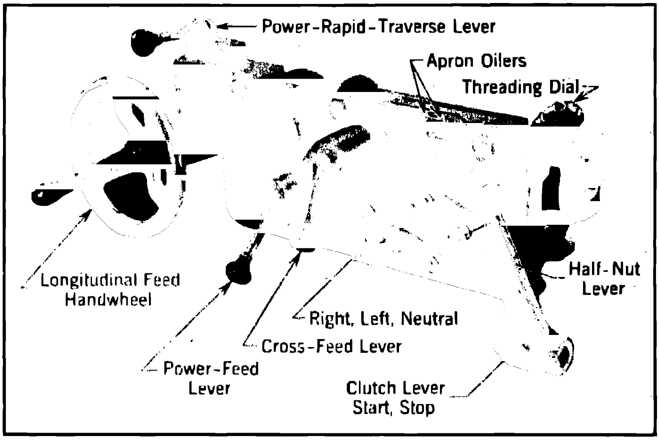


Courtesy American Tool Works Co.

FIG. 12. A Sectional Drawing of the Pacemaker Lathe Bed, Carriage, and Compound Rest.

This shows the cross slide carrying the compound rest, on which the tool is mounted in a single-screw tool post with a rocker base. The feed screws for the compound rest and cross slide are indicated.

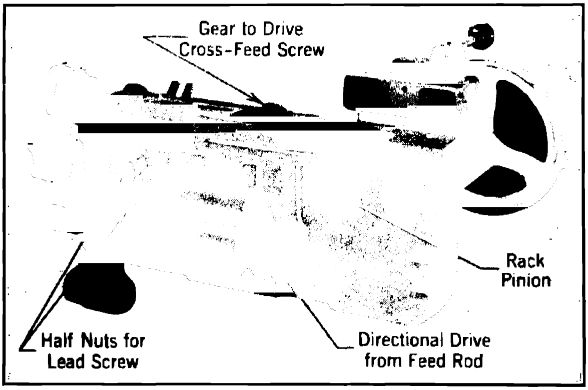
provides turning feeds equal to the above reduced in value from one-half to one-tenth. For a one-tenth reduction, the above threads would give 36 turning feeds from 15 to 800 rev of the work per in. of tool travel or 0.0666–0.00125 in. feed per rev. The power cross-feeds often are equivalent to the turning feeds. For cutting metric screw threads on a lathe with a lead screw having threads per inch, the change gears should include one set of gears having 50 teeth in the driver and 127 in the driven.



Courtesy American Tool Works Co.

FIG. 13. Front View of the Apron of the Pacemaker Engine Lathe.

A section through the longitudinal feed clutch is shown below.


Gear to Drive Cross-Feed Screw
Rack Pinion
Half Nuts for Lead Screw
Directional Drive from Feed Rod

Courtesy American Tool Works Co.

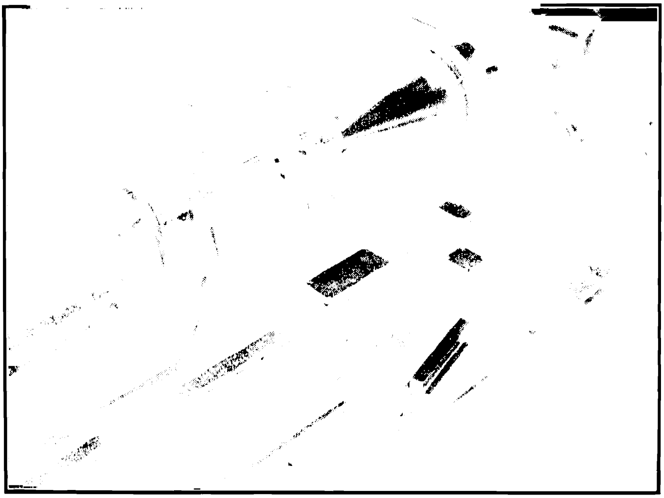
FIG. 14. A Rear View of the Apron of the Pacemaker Lathe.

Figure 10 shows how the lead screw and feed rod are driven by a train of gears from the spindle. Various feeds (or threads per inch) are obtained by shifting the built-in gears by the levers as indicated by the table on each machine. In general, to determine the train of gears n/N from the stud to the screw, if the lathe is simple geared and the stud runs at the same speed as the spindle, select the screw gear (N teeth), multiply by the threads per inch on the lead screw, L, and divide by the threads per inch to be cut, C. This gives the gear (n teeth) on the stud. Then

$$n = \frac{N \times L}{C} \text{ or } \frac{n}{N} = \frac{L}{C}. \quad \text{If } L \text{ is 6 and } C \text{ is 8, } \frac{n}{N} = \frac{L}{C} = \frac{6}{8} = \frac{3}{4} \times \frac{12}{12} = \frac{36}{48}.$$

Illustrations are given in Figs. 8 and 9 of the speed gears in the head of the Monarch type C lathe and the feed-gear drive from the spindle to the stud, from the stud to the feed box, to the lead screw or feed rod, and to the carriage and cross slide.

Figures 10–15 inclusive show various features of the American Tool Works Company Pacemaker lathe. In Fig. 10 the cover is opened to show the multiple V-belt drive from the motor in the cabinet leg to the constant-speed pulley. The tube to the right of the pulley is the rear end of the spindle from which the stud gear and the feed gears

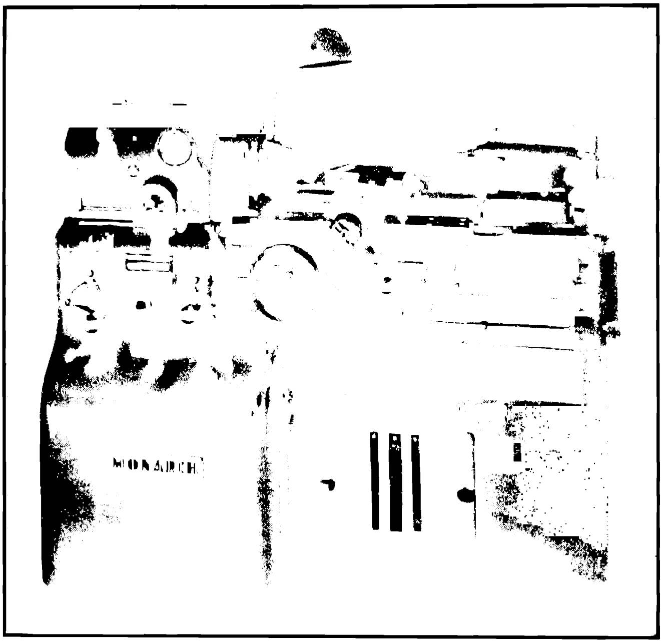


Courtesy American Tool Works Co.

Fig. 15. The Taper Attachment Mounted on the Rear of the Carriage of the Pacemaker Lathe.

This is of the carriage type with telescopic cross-feed screw control. It is bolted to and travels with the carriage. For use the clamp at the left is bound to the bed by two heavy bolts. When not in use, it slides along the bed with the carriage.

are driven. Figure 11 shows the rear of the headstock of the Pacemaker lathe when the driving motor, such as the d-c motor shown, is too large to be mounted in the headstock. The space under the motor is used as a cutting fluid reservoir. The cutting fluid pump is of the centrifugal type driven by the vertically mounted motor. This motor may be driven by direct current for limited speed control or by direct current from a motor-generator set or electronic tubes for wider speed variety. A section through the carriage illustrating the cross-feed screw is shown in Fig. 12. The front of the apron and a rear view are shown in Figs. 13 and 14, respectively, while the taper attachment mounted on the rear of the carriage is shown in Fig. 15.

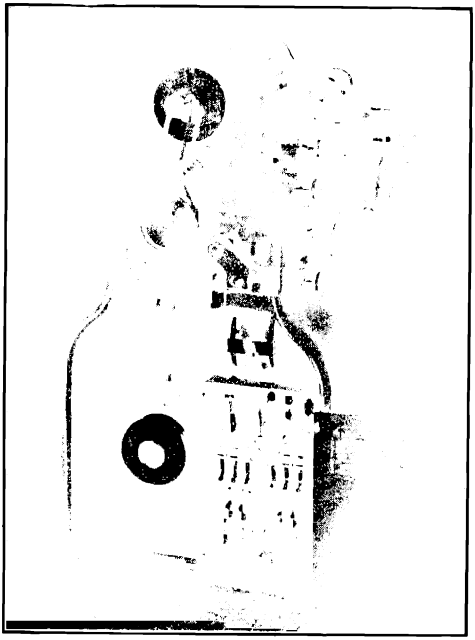


Courtesy Monarch Machine Tool Co.

FIG. 16. The Monarch 10-in. × 20-in. Model EE Precision Toolmakers Lathe for Bridging the Gap between the Bench Precision Lathes and the Conventional Floor-Type Toolmakers Lathe.

This lathe is driven by a 3-hp d-c motor with 100 to 1 infinite speed variation from the Ward Leonard drive, giving speeds from 40 to 4,000 rpm. It will cut 60 pitches of threads from 3 to 184 or feeds from 0.0005 to 0.016 in.

Figure 16 shows the small Monarch toolroom lathe which is now equipped with electronic drive. The d-c motor in the base under the headstock, Fig. 17, drives the spindle by two V belts. The electronic controls are mounted on a slide under the tailstock, Fig. 18, so they can be removed conveniently from the bed casting for maintenance.



Courtesy Monarch Machine Tool Co.

FIG. 17. An End View of the Model EE Precision Lathe, Showing the d-c Driving Motor, the 1 to 6 Gear Reducer, and Driving Sheave, Which Drives the Spindle Directly through the Two V-Belts.

The Ward Leonard variable-voltage control unit giving 100 to 1 speed ratio in infinitesimal steps is back of the d-c motor. The reduction gear furnishes a low speed range from 6.5 to 650 rpm, and the open belt gives an infinite number of speeds from 40 to 4,000 rpm. The drive to the quick-change gearbox for feeds is through an endless belt from the spindle. A gear train is reserved only for threading to give a direct drive from the spindle to the feed box through gears not shown.

ATTACHMENTS AND ACCESSORIES

The modern **engine lathe** is almost universal in that a wide variety of cutting operations, such as turning, facing, drilling, boring, reaming, and threading, can be performed with it. The work may be supported and driven in any one of several ways as follows:

1. Supported between centers and driven from a driving plate by a clamp or dog, Fig. 20.
2. Held on a mandrel, in turn supported between centers and driven by a dog, Fig. 21.
3. Supported on the tailstock center but held in and driven by a chuck on the spindle.

4. Held to the end of the spindle by a chuck, Fig. 23, or faceplate, Fig. 22.

5. Extending through the spindle and held in collets or spring chucks in the end of the spindle, Figs. 24 and 30.

6. Held in a chuck or collet and supported near the outer end in a steady rest, Fig. 23.

Courtesy Monarch Machine Tool Co.

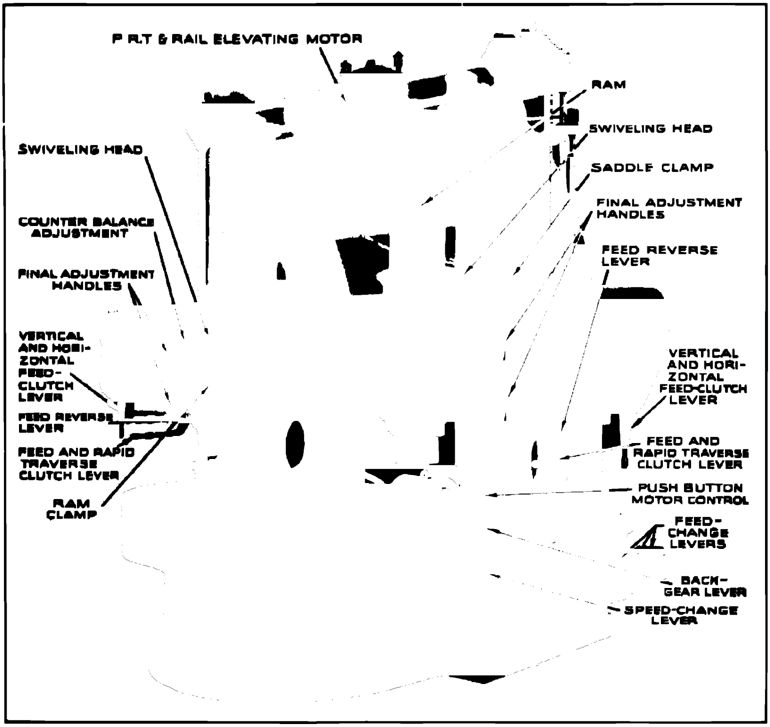
FIG. 18. The Electronic Transformers, 16-amp Xenon-Filled Tubes, Resistors, and Capacitors Housed in the Tailstock End of the Bed, Where the Ward Leonard Motor-Generator Set of Fig. 17 Is Normally Stored.

Sometimes when work held in a chuck or clamped to a faceplate is rotated, a drill, reamer, etc., is supported in the tailstock and fed into the work by the tailstock screw, Fig. 25. As the tool is kept from rotating in the tailstock only by friction, large drills, reamers, taps, etc., should be clamped mechanically and prevented from turning.

Standard Equipment

Standard equipment for the engine lathe consists usually of additional separate parts, such as a countershaft if needed, a driving or small faceplate, a large faceplate, a steady rest, a follow rest, two centers, and necessary wrenches.

The steady rest, when clamped on the ways of the bed, furnishes a three-point bearing or rigid support for long bars. The follow rest, usually mounted on the carriage, furnishes a two-point support against the work opposite the cutting tool to resist the cutting pressure of the tool on long or small-diameter bars. The use of the small faceplate is shown in Fig. 20 and the large faceplate in Fig. 22. For most engine-lathe work, the compound or swiveling-tool-post rest, Figs. 2 and 12, is desirable. A plain or nonswiveling type of rest is lower and more rigid for heavy work. An open-side toolholder, Fig. 11, or studs and straps, Fig. 3, are used on large lathes or for heavy work.


P R.T & RAIL ELEVATING MOTOR
RAM
SWIVELING HEAD
SADDLE CLAMP
FINAL ADJUSTMENT HANDLES
FEED REVERSE LEVER
VERTICAL AND HORI-ZONTAL FEED-CLUTCH LEVER
FEED AND RAPID TRAVERSE CLUTCH LEVER
PUSH BUTTON MOTOR CONTROL
FEED-CHANGE LEVERS
BACK-GEAR LEVER
SPEED-CHANGE LEVER
SWIVELING HEAD
COUNTER BALANCE ADJUSTMENT
FINAL ADJUSTMENT HANDLES
VERTICAL AND HORI-ZONTAL FEED-CLUTCH LEVER
FEED REVERSE LEVER
FEED AND RAPID TRAVERSE CLUTCH LEVER
RAM CLAMP

Courtesy Consolidated Machine Tool Corporation of America.

FIG. 19. Colburn Vertical Heavy-Duty Boring and Turning Mill.

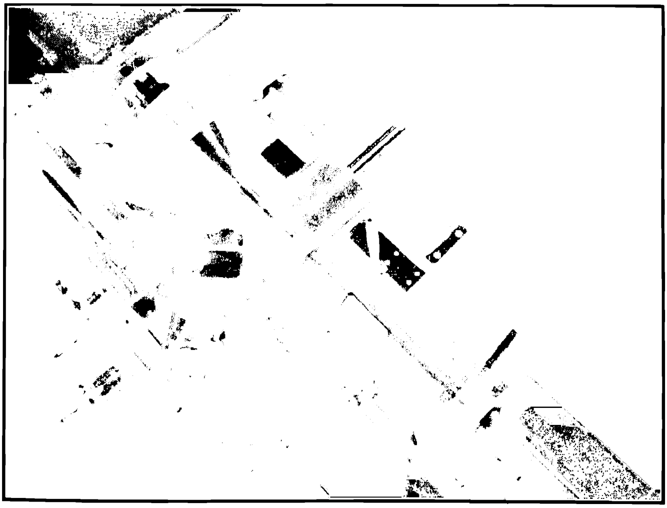
By the new three-lever control at each side of the machine, the feed and rapid traverse of both swivel heads and rams are obtained. Machines are built in six sizes having table diameters from 40 to 82 in. The constant-speed direct-connected driving motor, 10 hp for the 40-in. machine and 25 hp for the 82-in. machine, is attached to the machine base at the rear. Twelve speed changes and twelve feed changes from $^1/_{48}$ in. to 1 ipr of the table, each in geometric progression, are obtainable. The power rapid traverse and rail-elevating motor is mounted on the top of the housing. By power rapid traverse the heads and rams may be moved approximately 12 fpm horizontally, vertically, and in angular directions. Stub-tooth steel gearing, positive clutches, and ball bearings are used throughout the driving unit.

Micrometer length **feed stops** are usually provided on toolroom

Courtesy South Bend Lathe Works.

FIG. 20. Threading a Long Slender Shaft Mounted on Centers and Driven by a Dog Clamped to the Work and Engaging the Driving Plate.

A follow rest attached to the carriage supports the shaft back of the tool. The steady rest attached to the bed furnishes a three-point support to prevent deflection of the shaft.



Courtesy Pratt and Whitney Division, Niles-Bement-Pond Co.

FIG. 21. The Setup of a Part Pressed on a Mandrel Which is Supported between Centers and Driven by a Dog and Driving Plate.

A forged tool is shown turning the taper in a Pratt and Whitney 16 in. × 30 in. Model C toolroom lathe. The taper attachment is shown mounted on the rear of the carriage.

lathes. This self-contained unit, Fig. 31, is clamped to the front V to the left of the carriage. A protruding stem with a micrometer adjustment is set to stop the carriage in any desired position as it is fed toward the spindle. Power feed is disengaged just before contact with the stop, and the carriage fed by hand to the stop. Figure 16 shows a light toolroom lathe provided with a multinotch stop bar attached to the head. A micrometer head is located on the right end.

Courtesy South Bend Lathe Works.

FIG. 22. Boring an Eccentric Hole in Work Clamped to a Large Faceplate.

The work is clamped eccentrically. This is a good example for using toolmakers' buttons.

Courtesy South Bend Lathe Works.

FIG. 23. Cutting an Internal Screw Thread in Work Clamped in a Chuck but Supported at the Outer End in a Steady Rest Mounted on the Lathe Bed.

On lathes used for turning a number of shafts of several diameters, several screws mounted in one turret head may be attached to the carriage, so that each screw in turn engages the feed-stop bar for each length turned. In this way the length of each diameter on the several shafts can be duplicated. Single or turret-type stops are frequently applied to the cross slide, so that several diameters can be turned accurately in sequence. Figure 6 shows another means of disengaging the feed when the carriage has traveled to a limiting position at the right or left. A small sliding clamp attached to a bar shown just above the lead screw causes the bar to be forced into or out of the gearbox to disengage the feed when forced by the carriage.

Additional accessories needed to complete the lathe equipment for general work are the driving dogs and chucks.

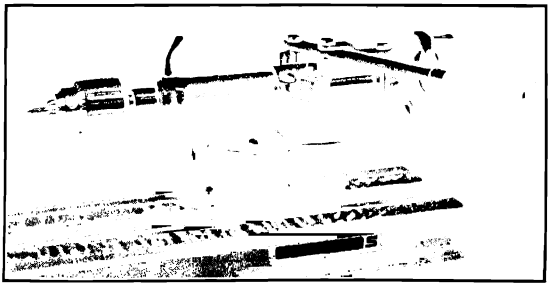
Chucking Equipment

The chucking of work to be machined has resulted in the embodiment in chucking devices of four distinct systems of power actuation.

Courtesy The Axelson Mfg. Co.

FIG. 24. The Sjogren Speed Collet Chuck Is Attached to the Standard Camlock or Tapered Spindle of the Axelson Toolroom Lathe.

The collet, of a wide range of sizes for round, square, or hexagonal bar stock, tightens and releases the grip by turning the plastic handwheel. This is a convenient device for machining small parts from bar stock in an engine lathe.



Courtesy South Bend Lathe Works.

FIG. 25. A Drill Chuck Carrying a Combined Drill and Countersink.

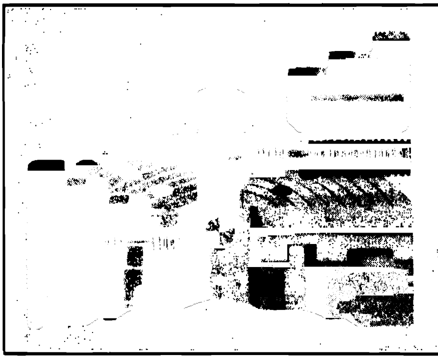
The chuck mounted on a taper shank is supported in the tailstock. The work to be center drilled is rotated in the chuck or collet.

(*a*) Mechanical power as effected by rotating screws, Fig. 26; gears, Fig. 27; screw and wedge, Fig. 30; and eccentrics and cams as used in the wrenchless chuck, Fig. XI-17.

(*b*) Magnetic power, the device being in effect an electromagnet, Fig. XV-32.

(*c*) Hydraulic power, in which the clamping medium is operated by hydraulic pressure.

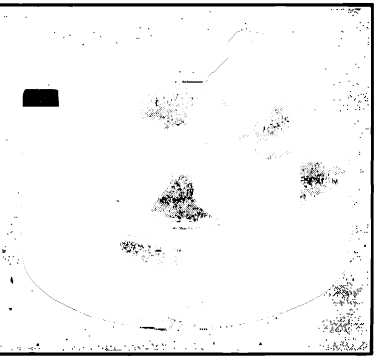
(*d*) Pneumatic power, in which compressed air is used, Fig. XI-18.



Courtesy Skinner Chuck Co.

FIG. 26. A Sectional View of a Four-Jaw Independent Lathe Chuck with Four Reversible Jaws.

The jaw screw and the jaw are shown separately. The screw is prevented from moving radially by the slotted-pin bearing. As the screw is turned, the jaw moves radially, each of the four jaws being moved independently of the others. To reverse the jaws, run them out of the chuck at the periphery, reverse ends, and run on again.



Courtesy Skinner Chuck Co.

FIG. 27. A Three-Jaw Universal "Geared Scroll" Chuck.

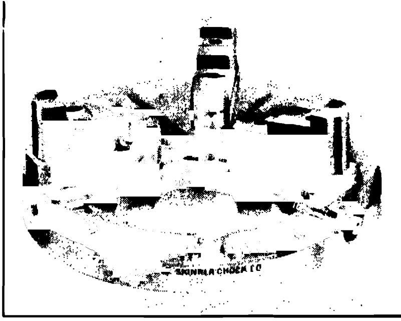
Showing in a phantom view how the application of a wrench to the pinion gear which is enmeshed with the gear on the underside of the scroll plate gives a radial movement to the jaws. The three jaws moving together and having a common center at all times give the chuck the name universal. The use of the scroll plate further designates it as a universal scroll chuck. This chuck may be furnished with two sets of jaws, one for internal and one for external work, or with two-piece reversible jaws as required.

The mechanical types are generally used in connection with the engine lathe.

When numerous parts are to be machined, production turning machines are used which are often equipped with chucks actuated by cams, such as the wrenchless chucks, or with chucks actuated by hydraulic, pneumatic, or electric power, described and illustrated in connection with turret lathes and screw machines. The magnetic chuck is used principally in holding ferrous metals for grinding operations.

The **toolroom lathe** required for a wide diversity of accurate work is usually provided with a taper attachment, Fig. 15; relieving attachment, Fig 6; draw-in bar with collets, Fig. 30; thread dial, Fig. 13; micrometer feed stop; oil and chip pan; oil pump, etc.

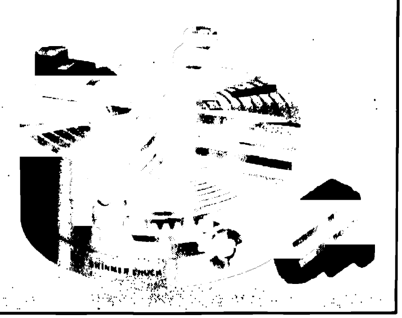
The **draw-in attachment,** shown in Fig. 30, is assembled in the spindle of the lathe to adapt the lathe for bar-stock work. The spring chucks may be purchased for round, square, hexagonal, or rectangular shaped bars, and in almost any size within the capacity of the draw-in bar. A self-contained collet-type chuck, which is adapted to the spindle nose like other lathe chucks, may be used on engine lathes to fit them for small-quantity production work as illustrated in Figs. 24 and XI-19.



Courtesy Skinner Chuck Co.

FIG. 28. A Three-Jaw Universal "Geared Screw" Chuck Equipped with Two-Piece Reversible Jaws.

The jaws have a common center at all times. The name is derived from the fact that the jaws are operated by a combination screw and gear.



Courtesy Skinner Chuck Co.

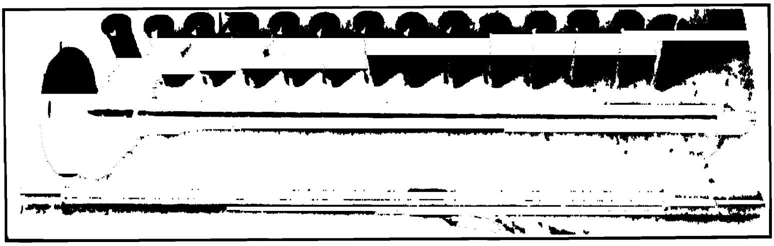
FIG. 29. A Four-Jaw Combination "Geared Scroll" Chuck.

Each jaw may be operated independently, or a universal action of all jaws is obtained when applying the wrench to the scroll pinion.

Tapers may be turned on a lathe by three different methods, such as using the taper attachment, offsetting the tailstock, or using the compound tool rest set at an angle. Only slight tapers may be turned by offsetting the tailstock of the lathe. This does, however, permit the turning of long tapers. Short tapers of almost any pitch may be turned by setting the compound tool rest at the proper angle and hand-feeding the tool, using the screw of the compound rest.

A **taper-turning attachment,** Fig. 15, usually purchased as an extra, is considered a necessary part of a toolroom lathe for the turning of accurate tapers. Some taper attachments are securely bolted to the rear of the lathe bed; others attached to the rear of the carriage.

A **relieving attachment,** Fig. 6, is a device attached to toolroom lathes to control the motion of the tool to provide clearances or relief to the cutting edges of dies, taps, hobs, formed milling cutters, etc. The tool-post slide is reciprocated by a shaft driven from the headstock. Lathes may be equipped with a subheadstock which provides a reduction in speed of the work, inasmuch as relieving operations should be carried on at much slower speeds than regular turning, in order to give the reciprocating toolslide time to function properly.



Courtesy The Hendey Machine Co.

FIG. 30. Draw-in Attachment and Set of Spring Chucks for the Hendey Lathe.

This set consists of a draw-in sleeve, the closer, the set of spring chucks or collets, and the closer knockout rod. These are shown assembled in the spindle in Fig. 12.

The **centers** between which work is supported, furnished as standard equipment, are usually of solid, hardened tool steel, ground to an included tool angle of 60 deg. The center in the headstock rotates with the work. The center in the tailstock, however, is stationary while the work rotates, and, as a result, should be lubricated with a paste such as powdered lead oxide and machine oil. To eliminate the rapid wear or burning of steel tailstock centers when high rotating speeds are used, as with sintered carbide tools or free-cutting stock,

Courtesy The Axelson Mfg. Co.

FIG. 31. The Micrometer Carriage Stop Clamped to the Front Bed Way in Any Desired Position to Insure the Stoppage of the Carriage for Repeatedly Turning to Any Desired Length.

The dial reads in thousandths of an inch, and the stop is designed to operate on either side of the apron.

current practice is to tip the point of the centers with Stellite or sintered carbide, or to replace the solid centers with the so-called "live" or antifriction bearing centers, Fig 32. These bearings are made in a variety of designs in which ball or roller bearings are used.

Where close tolerance on concentricity of internal and external surfaces of work is required, the bore is generally finished first and the work then forced on a **mandrel** which is supported between centers and driven by a dog from the driving plate. The external surfaces are finished with the work rotating on the true center of the bore. Plain mandrels are made in standard nominal sizes from ¼ to 4 in. diam. of surface-hardened and ground steel in cylindrical forms with lapped centers and relieved flats for driving on each end. They have a taper of about 0.010 in. per ft, the small end being slightly under basic size. Basic size is at a distance from the small end equal to the diameter of the mandrel. The size is marked on the large end. The mandrel forced into the bore creates sufficient friction to drive the work under cut. There are several types of expanding mandrels on the market. Each mandrel gives a wider range in size, so that fewer are required for general work.

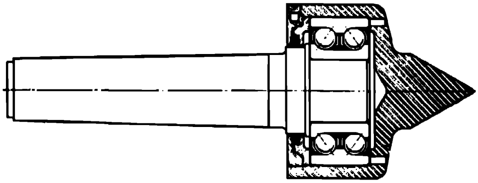


Fig. 32. The " Red-E " New Departure Ball-Bearing Tailstock Center.

During the past year an **ASA Standard of accuracy** for toolroom lathes and engine lathes has been approved. The standard was initiated during the war by the lathe manufacturers. Engine lathes are divided into three sizes, from 12 to 18 in., 20 to 32 in., and 40 to 72 in., inclusive. The tolerances cover the bed level in transverse and longitudinal distance with readings on a precision level within 0.0005 in. in 12 in. Other Standards call for tailstock way alignment, spindle center run out to be within 0.0004 in. dial indicator reading, spindle nose run out to be within 0.0003 in. as is the cam action of the spindle, spindle taper run out, and headstock alignment with the center. The lathe must turn round with work mounted in chuck within 0.0003 in. diam. It must turn cylindrical with work mounted in chuck to 0.0008 in. 12 in. from the chuck, and it must turn cylindrical with the work mounted between centers to within 0.0004 in. at each end. Other features and dimensions are held within these general limits.

QUESTIONS

1. What is the principal difference between a speed lathe and an engine lathe?
2. What is meant by a step-cone pulley, and for what purpose is it used?
3. What are back gears and for what purposes are they used?
4. Explain the path by which power is transmitted from the belt to the spindle when back gears are engaged.
5. What is meant by loose feed-change gears?
6. What is meant by quick-change gears?
7. In general, what is the use of the lead screw and the feed rod?
8. Name three ways by which a taper may be cut in an engine lathe, and state the advantages of each.
9. How may bars, rods, or shafts be held in an engine lathe while being machined?
10. Name two principal types of chucks and state why each is desirable.
11. How may castings, forgings, or other irregular shapes be held in an engine lathe while being machined?
12. What is meant by cutting speed in lathe work?
13. What is meant by feed in lathe work?
14. A cast-iron column for a bench drill press 2½ in. in diam. is being turned on a countershaft-driven lathe from a main drive shaft, as follows: The speed of the main drive shaft is 135 rpm; the diameter of the driving pulley on the main drive shaft is 16 in.; the countershaft-driven pulley has a 12 in. diam.; the countershaft cone pulley in use is 14 in. in diam. and drives to the lathe spindle-cone pulley 10 in. in diam. The back gears are not in use.

(*a*) Draw a sketch to indicate the shafts, pulley, and belts.

(*b*) Compute the revolutions per minute of the countershaft and lathe spindle.

(*c*) Compute the revolutions per minute and surface cutting speed of the work.

15. A lathe has 8 spindle speeds available through the geared head. These speeds are 13, 22, 36, 60, 110, 188, 315, and 525. The back-gear ratio is 8.72 to 1. What is the geometrical progression ratio between the different speeds? If the diameter of the work being turned is 4 in., what is the cutting speed in feet per minute for each speed of revolution?
16. The King vertical turret lathe in Fig. 19 has 12 speed changes ranging from 4 to 120 in geometrical progression. Determine the geometrical-progression factor and also determine the 10 intermediate speeds.
17. A lathe cuts 36 different threads with the lead screw, which range from 1¼ to 80 per in. With the feed rod, 36 power feeds, equivalent to 6–320 threads per in., are available. Determine the ratio between the thread and feed-rod values of feed. What are the minimum and maximum values of power feed in inches per revolution of the spindle?

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CHAPTER III

SHAPERS

The shaper as a machine tool was first developed to machine flat surfaces on small work. The tool is held in a toolholder supported on a clapper in the head at the end of a ram; see Fig. 1. The ram reciprocates, moving back and forth in a straight line, while the table carrying the vise and work feeds transversely on each return stroke.

The **clapper** which carries the tool post is hinged near its top. On the cutting stroke the tool forces the clapper against its rigid seat in the head. On the return stroke, as the tool is dragged back over the work, it may swing outward about the clapper hinge, thereby relieving the cutting edge of excessive wear, danger of chipping, and interfering with the work.

Shapers have become increasingly useful in both small-lot and production manufacture through improvements such as increased ruggedness in design and construction, greater horsepower, higher speeds, automatic feeds easily selected, and faster and more sensitive controls. They have been improved in power and speed to use sintered-carbide tools. Automatic tool lifting on the return stroke often is provided to protect the cutting edge of the tool and the machined surface. Tool lifting is accomplished by electric solenoids, flexible-cable linkage, mechanically or hydraulically. Tool lifting is standard practice on some shapers. Rapid traverse of the table horizontally and vertically is more generally available. Automatic lubrication with filtered oil protects all critical wearing points, including the bearing of the apron on the rail, the rail on the column, and the table on the table support.

CLASSIFICATION OF SHAPERS

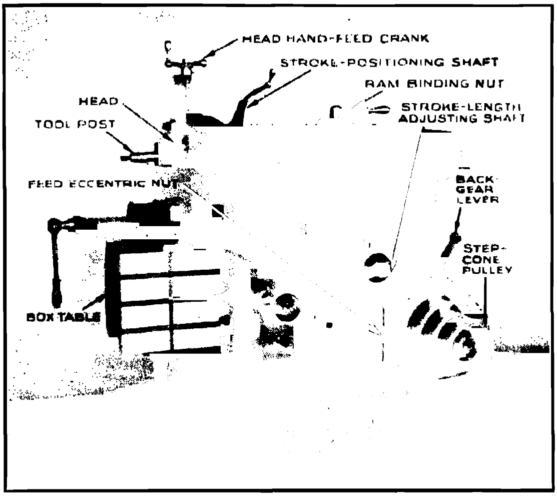
As with engine lathes, shapers may be classified in a number of ways, depending upon general features of design or the purpose for which they are intended.

1. They may be **horizontal,** Fig. 1, or **vertical,** Fig. 6. The ram operates horizontally or vertically.

2. They may be **plain** or utility shapers for general light work in which the forward end of the table is not supported; **standard, heavy-duty,** and **production** shapers in which the tables are rigidly supported on the forward end of the base,

as shown in Fig. 1; or universal shapers which have a table which may be tilted to cut tapers or compound angles, Fig. 11.

3. They may be driven by a step-cone pulley, with or without back gears, Fig. 1; a constant-speed single pulley, Fig. 3; or a direct-connected individual motor, Fig. 4.



Courtesy Gould and Eberhardt.

Fig. 1. The Gould and Eberhardt Old-Type Step-Cone-Pulley Driven Shaper.

This shaper is arranged with single-screw tool post, hand-feed swiveling head, single-screw swiveling vise, and plain box table with support. Eight speeds of the ram are available from the countershaft-driven four-step-cone pulley with single back gears.

To adjust the length of stroke, the ram is moved to the extreme right position ready to begin the cutting stroke. The squared shaft projecting from the center of the machine is turned by a crank handle. This moves the sliding block in the bull gear (see Fig. 3) to or from the center to give a stroke in inches as read directly on the scale shown under the pointer on the ram. The knurled ball knob locks the sliding-block mechanism in position. To get the stroke position, or locate the tool with respect to the work, the ram still being in the extreme right position, the handle nut on the top center of the ram is released, and the positioning shaft, located forward on the ram, is turned by the crank handle until the tool is about ½ in. from the work. The handle nut is then tightened, binding the ram to the upper end of the crank. See Fig. 2.

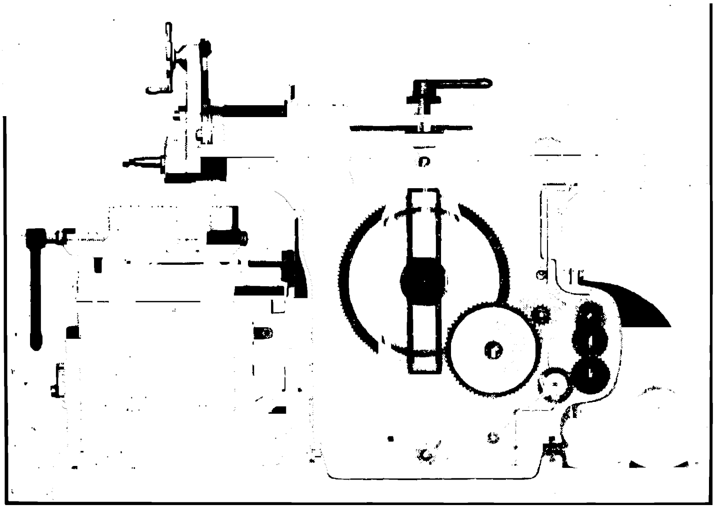
Cross-feeds of the table are obtained by moving the feed eccentric nut from the center of the vertical oscillating screw located in front of the cone pulley. The feeds are engaged, reversed, or held in neutral by positioning the ratchet pin on the large gear. The feed of the table should occur during the back or noncutting stroke. The table may be fed to the right or left, and the feed eccentric nut is moved above or below the center of the vertical screw in order to secure the feed of the table on the reverse stroke.

4. They may be driven mechanically by means of a crank and rocker arm, Fig. 2, or hydraulically, Fig. 7.

5. They may cut on the push or draw stroke.

Drives

The step-cone pulley is driven by belt from a mating step-cone pulley on a countershaft. The countershaft is in turn driven from a main drive shaft, similar to a lathe installation, shown in Fig. II-4, except that but one clutch pulley is needed on the shaper countershaft, whereas that of the lathe has two to permit reverse speeds. The step-cone-pulley type of drive is no longer made by the principal shaper manufacturers. It has been replaced by gearbox, Fig. 4, or built-in gear drive, Fig. 3, for obtaining various speeds. The single pulley may be driven by a belt from a shaft, but most of the new shapers are arranged for direct motor drive.

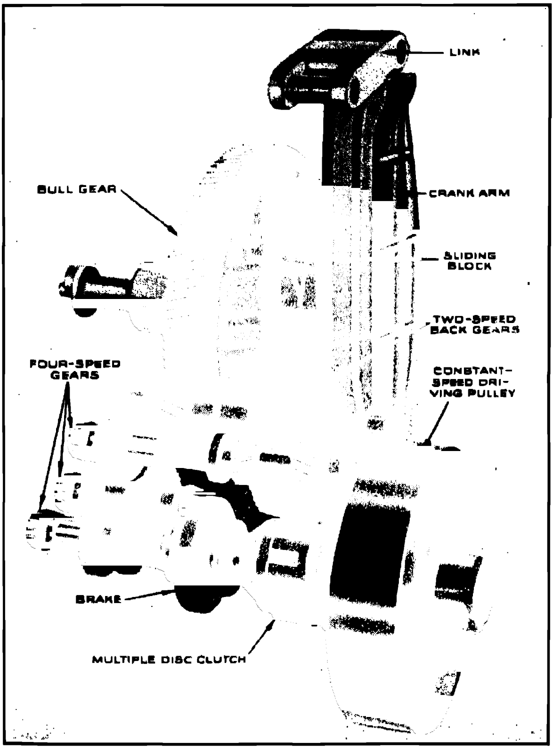


Courtesy The Ohio Machine Tool Co.

FIG. 2. A Sectional View of the Ohio Shaper, Showing the Gear Train and Crank-Arm Driving Mechanism and the Automatic Lubricating System.

The motor engages the primary drive shaft through a short-belt drive. This shaft is provided with a multiple-disk adjustable clutch and brake for starting and quick stopping the machine. Eight speeds are provided from the constant-speed motor through speed gears of the stub-tooth spur type, and back and driving gears of the helical type. Hand feed is provided to the swiveling head through the handwheel and screw. The rail elevating screw and the table cross-feed screws are shown in section. The stroke positioning shaft (Fig. 1) moves the nut on the upper end of the crank along the ram by means of the horizontal screw. This nut is clamped to the ram by the ram binding nut. The oil pump circulates filtered oil to all bearings.

The individual-motor drive with push-button control is the best current practice and is most generally used; see Figs. 2 and 4. The motor is mounted on a bracket attached to the rear of the shaper bed, and transmits power to the drive shaft through a short flat belt, multiple V belt, cog belt, silent chain, or directly connected gears. The short flat-belt drive, with a weighted idler pulley to maintain a tension of about 70 lb per in. width of belt, or the multiple V belt, is furnished as the most desirable standard equipment by a number of manufacturers. The belt in this case serves as a buffer for shocks between the tool and motor. The flanged motor mounting, in which the motor shaft is splined or coupled directly to the drive



Courtesy The American Tool Works Co.

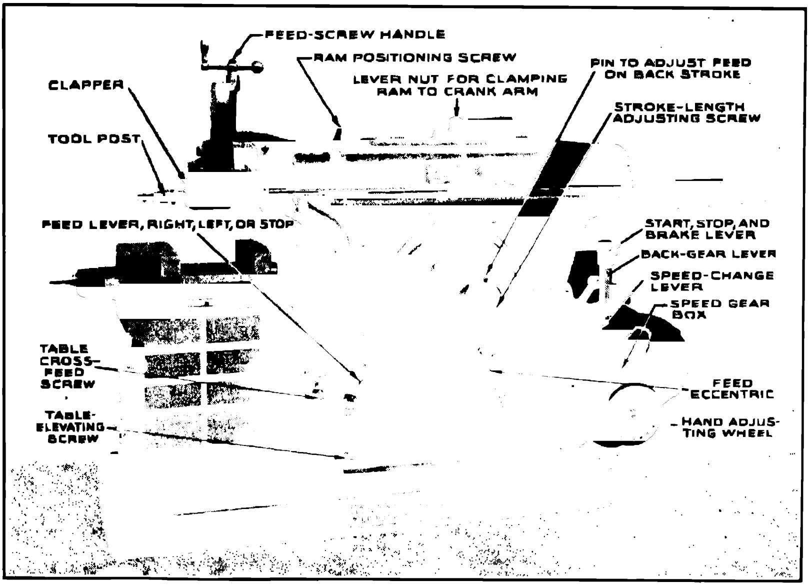
FIG. 3. The Power Transmission Used in the " American " Shaper.

This shows how power is transmitted from the constant-speed driving pulley to the ram, successively, through a multiple-disk clutch, seven spur gears providing four speed changes, helical back gears providing two additional speed ratios, the large bull gear, the adjustable crankpin in the bull gear, the sliding block in the crank arm, the crank arm to the ram through the horizontal link at the top. The bull gear may have a total of eight different speeds. The crankpin, which fits in the sliding block, is held in the bull gear by dovetailed ways. As this crankpin is moved outward radially, the crank arm or lever, mounted on a fulcrum or pivot shaft at its lower end, swings through a greater angle, thereby increasing the stroke of the ram. The sliding block slides in ways provided in the crank arm.

shaft, is space saving and efficient. A mechanical variable-speed self-contained drive with constant-speed motor is shown in Fig. 8.

Stroke and Feed

In horizontal shapers a chip is removed by the tool on each forward or cutting stroke of the ram and tool as the table on which the work is held is fed transversely on the rail. The depth of the chip or depth of cut is the distance that the tool point is below the work surface, and the feed per stroke is equal to the movement of the table. The eccentric rod feed of the Gould and Eberhardt shaper, Fig. 4, is now replaced by a feed drum varying in eccentricity from one end to the other and controlled as illustrated in Fig. 5. The speeds are selected by two levers shown at the right.



Courtesy Gould and Eberhardt.

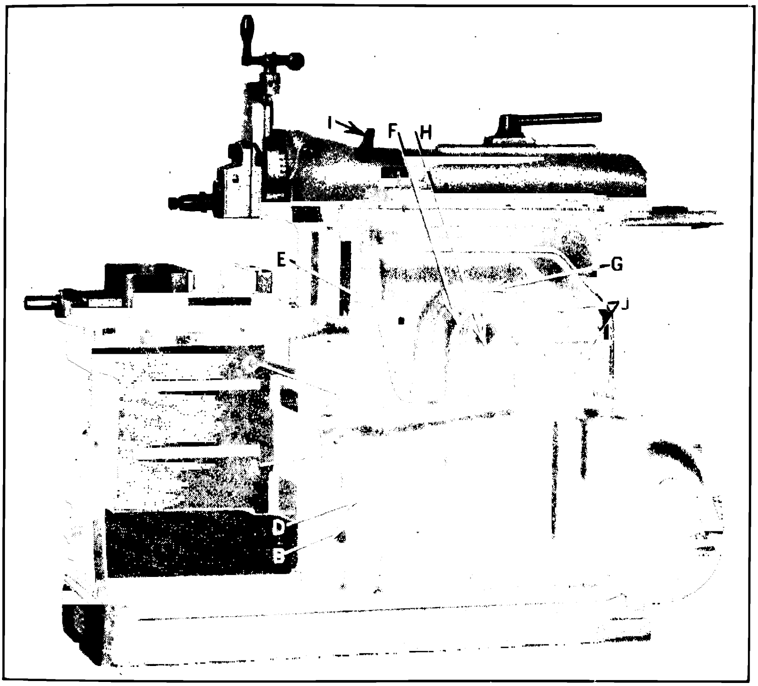
FIG. 4. The Gould and Eberhardt 24-in. Invincible Shaper for Heavy-Duty Work Arranged for Motor Drive.

The length and position of the stroke are obtained as described in Fig. 1. The feed eccentric nut, when at the upper end of its stroke, gives zero feed to the table, but increases as displaced downward. The feed is secured on the return stroke of the ram, as the table is fed to the right or left, by pressing the button shown above the stroke adjusting shaft, to rotate the feed clutch 180 deg. A large hand-wheel is provided on the speed-gear box to turn the gears for slight tool adjustment or to shift gears or engage the back gears.

A sheet-metal guard attached to the frame beneath the rear end of the ram protects the ram against possible injury when extended to the rear, and prevents one from being injured by the reciprocating ram.

The head on the end of the ram, which carries the clapper, tool post, and tool, may be fed, usually by hand, up or down, or at an angle if the head is swiveled to a fixed position. In the horizontal shaper without extra attachments, flat surfaces which are horizontal, vertical, or inclined may be cut. Irregular surfaces may be produced by combining the table feed with the head feed or by the use of formed tools.

In vertical shapers, the ram reciprocates vertically, and the work is usually supported on a rotating or swiveling table which, in turn, rests on a cross slide and carriage. The work may, therefore, be indexed or made to rotate while being machined, or be fed longitudinally or transversely. The vertical shaper with standard equipment may do a greater variety of work than the plain horizontal shaper, although each has its place in manufacturing.



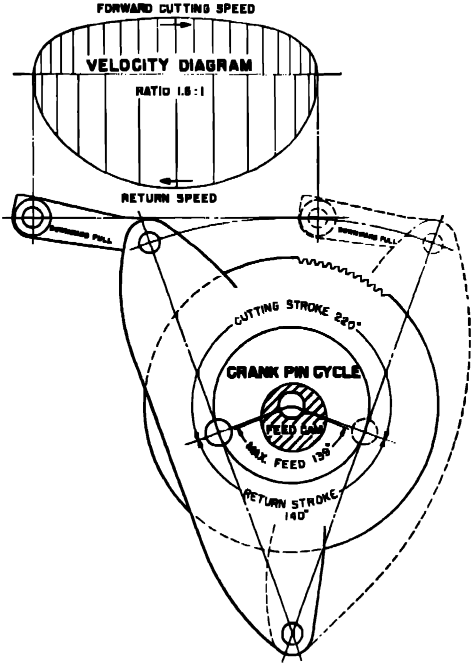
Courtesy Gould and Eberhardt.

FIG. 5. The 16-in. Plain Toolroom Shaper with Single Screw Vise and Plain Table and Built-in Push-Button Control.

This machine is built in sizes from 14 in. up to and including 36 in. Sixteen speeds giving 12 to 200 strokes per minute are available with a 3- or 5-hp motor. Eighteen feeds from 0.005 to 0.090 are available.

A, Graduated frictional dial; *B*, horizontal hand-feed control; *C*, feed engaging lever, right or left; *D*, table-elevating spline; *E*, power rapid traverse lever; *F*, direct-reading feed dial; *G*, feed selector; *H*, stroke length adjusting shaft and direct-reading stroke index under cover; *I*, stroke positioning screw; *J*, speed-selecting levers.

The **length and position of the stroke** of the tool in both horizontal and vertical shapers may be varied to suit the job, as described in Fig. 1. The cutting speed is usually expressed as strokes per minute of the ram. The average cutting speed in feet per minute is a function of the strokes per minute and the length of stroke. The ram has a slower forward or cutting speed than return speed, as shown in Fig. 6. The drive, known as the Whitworth, provides a slower, more powerful cutting stroke and a faster return stroke to reduce operating time. The time ratio of cutting to return stroke in Fig. 6 is 220/140 = 1.57. The hydraulic shaper, Fig. 7, has a constant cutting and return speed.

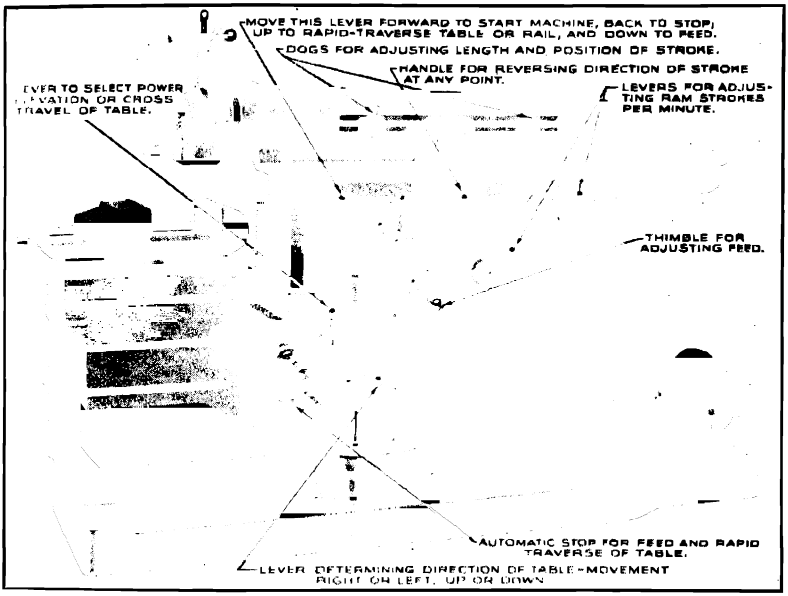


Courtesy Cincinnati Shaper Co.

FIG. 6. Diagram of the Variable Throw Crank and Crank Arm, Showing the Velocity Diagram of the Ram for the Full Forward and Return Strokes.

The average forward speed is less than the average return stroke. A section through the eccentric feed cam mounted on the bull gear shaft is shown.

The length of the stroke of a shaper tool is positive and may be set to terminate the cut close to a shoulder. Horizontal shapers are made in sizes having maximum strokes up to 36 in. in length. The Cincinnati heavy-duty 36-in. stroke, rapid-traverse shaper with a double screw vise has a 10- or 15-hp a-c motor attached to the rear of the bed and drives the clutch pulley by V belts. This type of machine is made in 8 sizes from 16- to 36-in. stroke, with rapid traverse to the table, automatic lubrication, internal transmission with gears of heat-treated AISI 3140 steel. Cam feeds and true reading dials provide for 11 feeds from 0.010 to 0.170 in. per stroke and 8 speeds from 8 to 102 strokes per minute. The new Cincinnati utility shaper, having no knee support, in 16-in. and 20-in. stroke sizes can be equipped with a 3 or 5-hp motor. Cutting speeds of 250 fpm are possible on a 10-in. stroke, so that carbide tools may be used effectively.

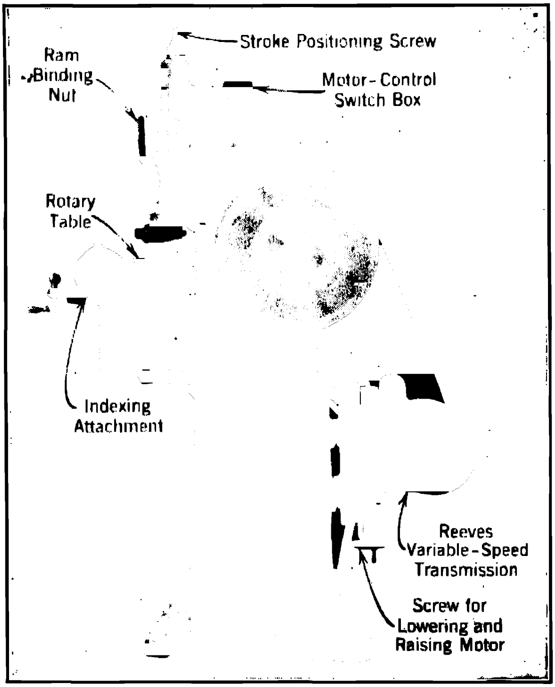

MOVE THIS LEVER FORWARD TO START MACHINE, BACK TO STOP; UP TO RAPID-TRAVERSE TABLE OR RAIL, AND DOWN TO FEED.
DOGS FOR ADJUSTING LENGTH AND POSITION OF STROKE.
HANDLE FOR REVERSING DIRECTION OF STROKE AT ANY POINT.
LEVER TO SELECT POWER ELEVATION OR CROSS TRAVEL OF TABLE.
LEVERS FOR ADJUSTING RAM STROKES PER MINUTE.
THIMBLE FOR ADJUSTING FEED.
AUTOMATIC STOP FOR FEED AND RAPID TRAVERSE OF TABLE.
LEVER DETERMINING DIRECTION OF TABLE-MOVEMENT RIGHT OR LEFT, UP OR DOWN

Courtesy Rockford Machine Tool Co.

FIG. 7. Rockford Hy-Draulic Shaper.

Made in two sizes, 24-in. and 32-in. strokes. A 10-hp motor drives an oil pump which provides uniform cutting speed and pressures throughout the feed stroke of 5,800 lb when the cutting speed is from 0 to 60 fpm with a ratio of cutting to return stroke of 1 to 3.73, and 2,750 lb when the cutting speed is 0 to 120 fpm with a ratio of cutting to return stroke of 1 to 1.8. The ram speeds remain constant as selected for all lengths of stroke. Any number of ram strokes per minute up to 150 are obtainable. Any feed actuated hydraulically up to 0.160 in. is instantly obtainable by adjusting a thimble.

The $3\frac{1}{2}$-in.-stroke vertical shaper, Fig. 8, can be converted quickly into a 7-in.-stroke horizontal shaper. There are a number of small light-duty bench-type shapers on the market having strokes of 7–10 in., such as the Atlas and South Bend. Many milling machines have standard vertical attachments available to convert the rotary motion of the spindle into the reciprocation of a ram for slotting,



Courtesy The Reeves Pulley Co.

FIG. 8. The "Rhodes" Convertible 7-in.-Stroke Horizontal Shaper or 3½-in.-Stroke Vertical Slotter with Motor Reeves-Pulley Variable-Speed Drive.

This machine is equipped with a rotary table with indexing attachment mounted on a box knee or table which may be fed in and out or swiveled. The knee may be fed mechanically along the rail. In and out, longitudinal and rotary feeds are by hand. The ram pivots up to 10 deg from the vertical position as shown, indicated by a graduated scale, for die work.

The machine as manufactured was provided with a three-step-cone-pulley drive. The cone pulley has been replaced by the large pulley for short belt direct-motor drive with push-button control. A Reeves single-shaft variable-speed transmission which permits a minimum speed of one-third of the maximum is built onto the shaft of a constant-speed motor. The motor and variable-speed unit, mounted on a sliding base, are attached to the rear of the column. The variable-speed unit consists of two opposed cones, the inner one fixed to the motor shaft, while the outer one is keyed to permit longitudinal adjustment. A compressed coil spring tends to keep the two opposed cones together. The beveled edges of the flat belt rest on the two cones. By lowering the motor on the sliding base by means of the handwheel, the belt tension is increased, causing the two cones to be forced farther apart. The belt runs closer to the center of the motor axis, resulting in lowered peripheral belt speed.

cutting keys, etc. Vertical shapers are made usually with a shorter stroke capacity, ranging from 3 to 18 in. in length.

The Betts (Consolidated Machine Tool Corp.) heavy-duty crank slotter, quite like the Dill slotter shown in Fig. 10, is made in sizes from 6-in. to 36-in. stroke.

Features

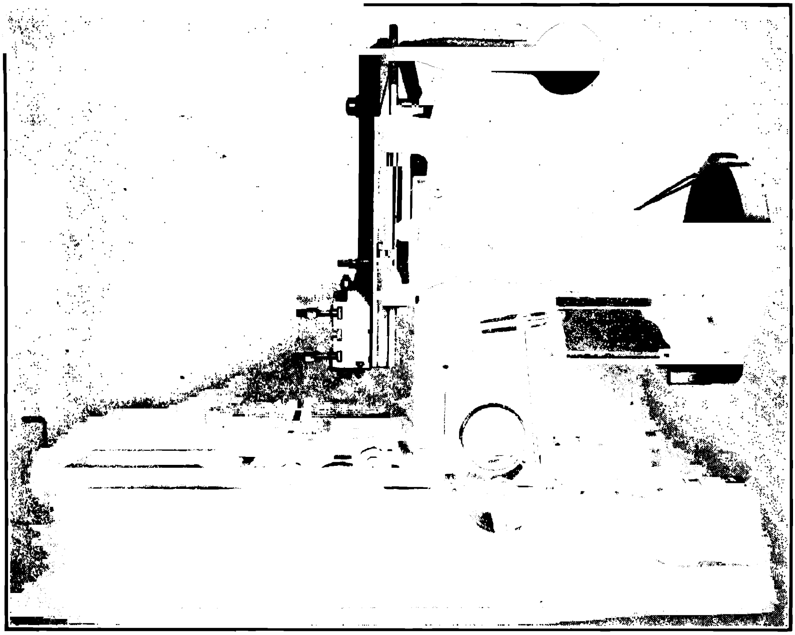
Heat-treated alloy steel is used almost exclusively for gears and shafts. Multiple splines, antifriction bearings, helical gears, automatic lubrication with filtered oil, micrometer dials on feed screws, cams for providing feeds, disk clutches, indicating dials for strokes per minute and length of stroke, and feed per stroke in inches are some of the many recent improvements.

FIG. 9. A Silent-Chain-Link Die Being Formed and Relieved on the Tilted, Rotary Table of the Hanson-Whitney Die-Shaping Machine.

The knee is adjustable vertically, and the length of stroke of the ram is variable. A set of slotting tools for die work is shown at the left.

Power rapid traverse to move the table carrying the work at a speed much greater than the usual feed rate is a recent time-saving improvement. This permits the adjustment of the work under the tool by push-button control of a separate high-torque motor built into the rail, but in some shapers the rapid traverse is controlled by a lever, Fig. 5.

In **centralized control,** all control levers, such as those for starting, stopping, braking, speed and feed changing, and feed engaging or disengaging, are placed at, or extended to, the working position of the operator. In many shapers all these levers are within a radius of 12 in. In some instances, **dual control** for the table feed is provided in which the operator may control the feed of the table either from the right end of the rail or from the front of the table. Centralized control is particularly emphasized in new shapers. This saves the time and energy of the operator and results in great productivity of the machine.



Courtesy The Nazel Engineering and Machine Works.

FIG. 10. The Dill Slotter Having a 10-in.-max. Stroke and a 24-in.-diam. Rotating Table.

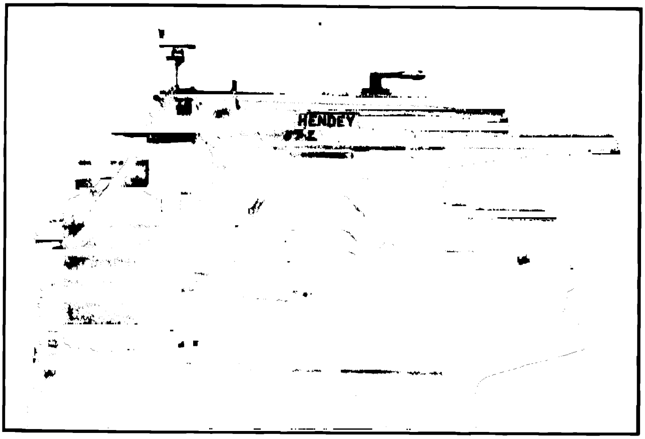
The balanced vertical ram is actuated by an adjustable crank to vary the length of stroke. The position of the ram may be adjusted vertically, and quick return stroke is provided. The clapper box carrying the tool is mounted on the lower end of the vertical ram. The head carrying the ram is adjustable longitudinally. Power is furnished through a constant-speed electric motor, driving through a gearbox, giving six changes of speed to the ram. A rotating table is mounted on the slide. Quick traverse and feeds are available longitudinally and transversely. The tool may be fed intermittently as at the end of the noncutting stroke, or continuously through the stroke, as desired.

SHAPER EQUIPMENT AND ATTACHMENTS

The usual standard equipment of a horizontal shaper consists of either a single-, Fig. 1, or double-screw vise, table support, belt guard for belt-driven machines, countershafts for step-cone-pulley drive, and necessary wrenches.

Usually a single-screw tool post, as illustrated in Fig. 1, is made optional to tool straps, Fig. 10. The tool straps, as used more generally on planers, are better for heavy work.

Extra attachments, such as a countershaft for single-pulley drive, if needed, power rapid traverse to the table horizontally and the table and rails vertically, power down feed to the head, or power revolving feed to the head, the universal revolving table or the tilting-top table shown combined in Fig. 11, may be furnished at extra cost. **Index centers** for shaper work are also available.



Courtesy The Hendey Machine Co.

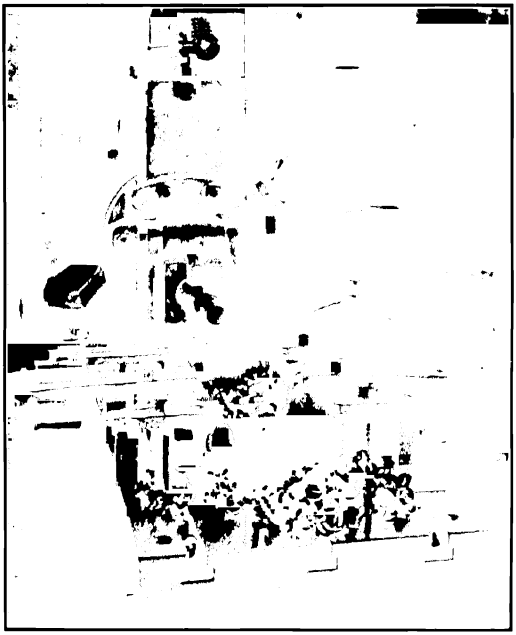
FIG. 11. The Universal Table and Plain Vise as Used on the Hendey 16-in. to 28-in. Crank Shapers.

The vise is mounted on a swiveling block, which can be set up to 15 deg either side of horizontal. The block in turn is mounted on the table, which can be rotated 360 deg in a vertical plane with settings easily read on a graduated dial at the left end of the trunnion. This machine is also provided with mechanical down-feed located just to the right of the head.

Holding clamps are necessary adjuncts to shaper work. A great deal of work done in horizontal or vertical shapers is held in a vise. Often, however, the most difficult part of a shaper operation is clamping the work rigidly in the proper position. See Figs. 9 and 12.

In setting up work for shaping, **parallels** and small screw jacks also are frequently helpful to elevate thin work held in a vise so the cutting tool can pass over the jaws, or to support the work. Internal shaping such as cutting a keyway in the bore of a gear is done by using a toolholder with a 90-deg-bend extension in the end of which is held a slotting cutter.

Boom cranes may be attached to the shaper for handling heavy work.



Courtesy The Cincinnati Shaper Co.

FIG. 12. A Typical Cast-Iron Shaper Job.

The vise has been removed and the work is clamped by U straps directly to the table. Excessive overhang of the tool bit and toolholder is provided in order that the tool post may clear the clamps.

QUESTIONS

1. What is meant by a step-cone pulley drive shaper?
2. What is meant by a horizontal- or vertical-type shaper?
3. What is meant by depth of cut in shaper work?
4. What is meant by feed in shaper work, and how is the feed accomplished?
5. What is the purpose of a clapper which supports the toolholder and tool?
6. How is cutting speed designated in shaper work?
7. What is meant by centralized control?
8. What is meant by a universal vise?
9. What three motions may the table of a vertical shaper have?
10. Describe various types of power transmission when direct motor drive is used.
11. In shaping a piece of work, the tool used has a depth of cut of 1/4 in. and a

feed of 0.020 in. per stroke in removing the surface from a cast-iron plate 8 in. by 16 in. in size. The material is fed so that the tool cuts lengthwise and is fed across the 8-in. face.

(*a*) Draw a sketch of the piece to show what is meant by depth of cut and feed.

(*b*) The shaper is making 30 cutting and return strokes per min. Assuming the cutting speed to be constant for the entire cutting stroke and the return stroke to take 60 per cent of the time of the cutting stroke, find the approximate cutting speed in feet per minute, assuming ½ in. additional noncutting distance at the beginning and ¼ in. at the end of each stroke.

(*c*) Determine the time in minutes to machine the whole face.

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CHAPTER IV

PLANERS

A planer is a machine tool developed to machine flat surfaces. It may do work ordinarily done on a shaper, although the planer generally machines work much larger and more cumbersome to handle. Very heavy cuts, which require great driving power, strength, and rigidity, can be taken on a planer. The work to be machined is held in a vise or fixture bolted to the table, or it may be clamped directly to the table. The table carrying the work is reciprocated past the cutting tool or tools for speed, as the tools are fed horizontally, vertically, or at an angle for each stroke.

THE CLASSIFICATION OF PLANERS

The modern planer may be classified in a number of different ways, as follows:

1. **The type of housing**: Planers may be of the double-housing type, Fig. 1, or of the open-side type, Fig. 2.

2. **Method of construction**: There are the light-, medium-, or heavy-duty planers, or standard planers with widened housings.

3. **Purpose**: There are the standard planers for general work, locomotive cylinder planers, and extremely heavy-duty planers, such as for planing railroad frogs and switches of manganese steel.

4. **Method of power application**: (*a*) The drive shaft of the planer may be driven by **open and crossed belts from a hanger-type two-speed countershaft,** Fig. 3. The countershaft is attached overhead to the ceiling.

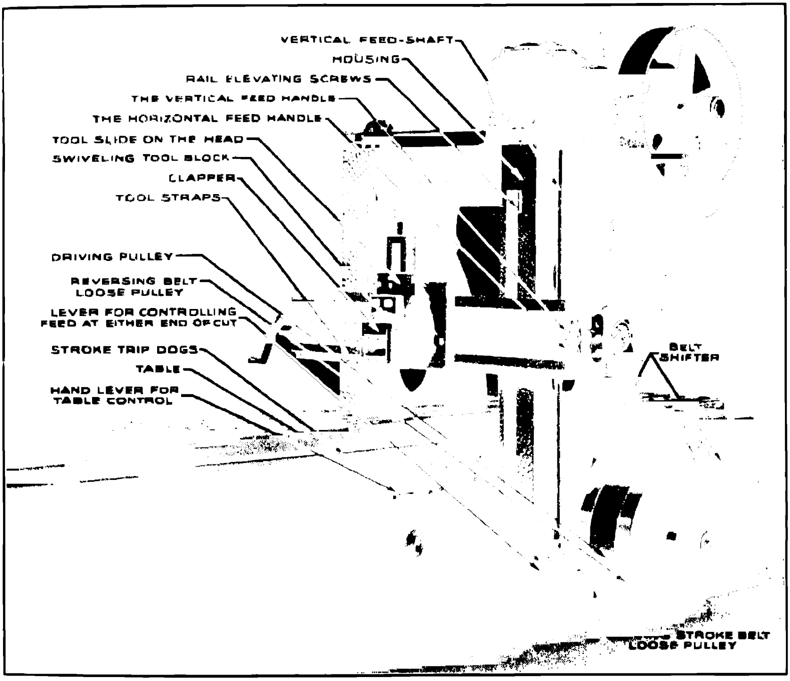
(*b*) **Open- and crossed-belt drive from self-contained countershaft,** Fig. 1. The countershaft is mounted on the top of the planer housing.

(1) The countershaft may be driven by belt from a drive shaft.

(2) The countershaft may be driven by a constant-speed motor connected directly to the shaft or driving through a gear reduction or belt. In this case, only one speed of the countershaft is possible, resulting in but one cutting and one reversing speed of the table. The self-contained motor drive with the countershaft driven directly by a constant-speed motor through a single gear reduction is shown in Fig. 1.

(3) The countershaft may be driven by a constant-speed motor through a multiple-speed gearbox to the countershaft.

(4) The countershaft may be driven by a constant-speed motor and various speeds obtained through a step-cone-pulley drive.



Courtesy The Liberty Machine Tool Co.

FIG. 1. The Liberty Old-Style (about 1925) Two-Housing Planer with Self-Contained Motor-Driven Countershaft.

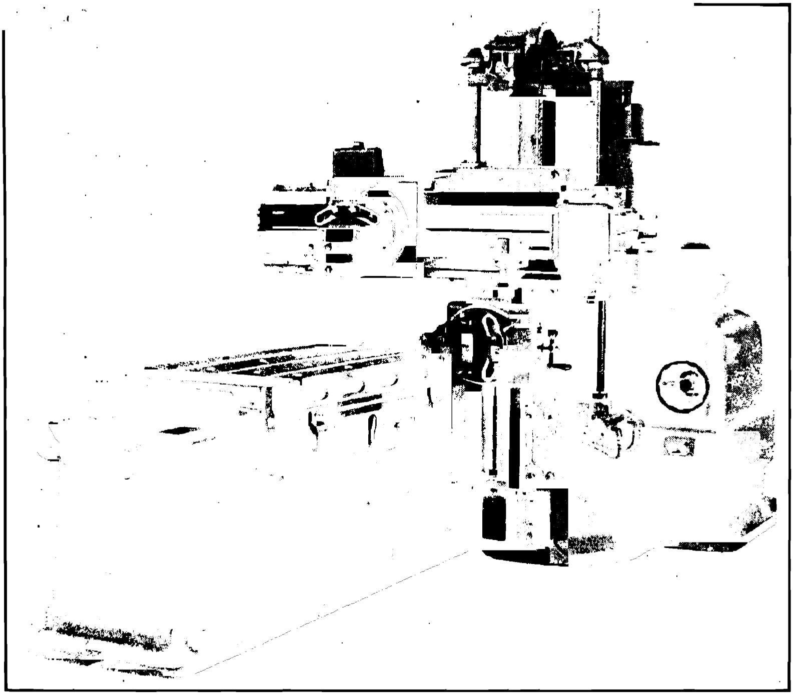
One swiveling head is shown on the rail. The toolslide on the head is fed vertically or the whole head horizontally by power furnished through the vertical splined feed rod driven at its lower end from the bull-gear shaft. The two short vertical handles at the end of the rail operate reversible ratchet feed gears, and are in their neutral position when vertical. The lower one at the end of the lead screw engages the feed to the right or left as it is tilted. The one at the end of the horizontal splined feed rod feeds the toolslide down when tilted left, or up when tilted right. The head may be moved horizontally by hand by turning the squared-end lead screw with a hand crank at either end of the rail. The toolslide is moved vertically by turning the feed rod in the same manner.

Various feeds are obtained up to a maximum of ¾ in. per stroke, by turning the handle wheel on the lower end of the rail. Actual feeds are indicated on the circular dial directly above. The length and position of the stroke of the table are obtained by the location and distance between the trip dogs bolted to the T slot in the side of the table. These dogs, or the hand-operated handle below, cause the table to reverse at the end of the stroke, by shifting the two driving belts, one of which is open and one crossed, to and from the central aluminum driving pulley.

(5) The countershaft may be driven directly by a multispeed alternating-current motor to give three or four cutting and return speeds to the countershaft and table.

(6) The countershaft may be driven by a direct-current variable-speed nonreversing type of motor to provide a wide range of speeds.

(*c*) **A direct-connected variable-speed reversing motor drive.** When a gear train is used to drive the table, the motor is attached by a coupling directly to the planer driving shaft, as arranged in Fig. 4.



Courtesy The Rockford Machine Tool Co.

FIG. 2. The Rockford Open-Side Hy-Draulic Planer.

Exact adjustments of all speeds and feeds are made by hydraulic pressure. Table reversals are smooth and shockless. Ratio of cutting speed to return is 1 to 3. The cutting speed is furnished by an oil gear pump directly connected to the table cylinder. Any cutting speed up to 75 fpm is available. Twenty horizontal feeds ranging from 0.010 in. to 0.200 in. and twenty vertical feeds ranging from 0.004 in. to 0.080 in. are provided by hydraulic power from a separate pump. The feed takes place at the end of the noncutting stroke and before the cut starts.

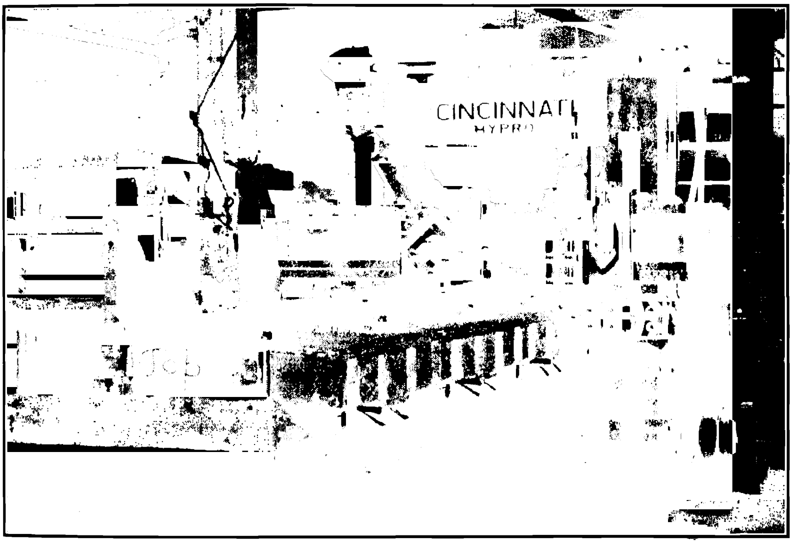
The table speed-control handwheel is shown on the front of the pump-unit case on which the driving constant-speed motor is mounted. The large table control lever is shown on the side of the bed. The hydraulic-feed-mechanism cylinder is shown at the lower end of the vertical feed rod.

When the worm-rack drive is used, the motor may be connected to a herringbone reduction gear by means of a coupling.

(*d*) **Motor-driven hydraulic pump.** In the hydraulic drive of Fig. 2, a constant-speed electric motor drives the variable-displacement oil pump which provides the variable speeds.

5. Method of driving the table: (*a*) A train of spur gears. This type of drive, of late years, has been replaced largely by those listed below.

(*b*) A train of helical gears, Fig. 5. In this drive, each alternate set of the three reduction gears has right- and left-hand helices in order to balance the end-thrust reaction on the bearings. This drive uses a helical-tooth bull gear which engages with a rack on the underside of the table, the teeth of which are on a slight angle. To avoid this side thrust on the table, the Pond planer gear drive has one single helical gear reduction, one twin right and left helical gear reduction, and one single spur gear reduction. The spur bull gear meshes with the straight-tooth rack.



Courtesy The Giddings and Lewis Machine Tool Co.

FIG. 3. The Cincinnati Hypro Planer, Belt Driven, with One Railhead and One Sidehead Cutting Simultaneously.

The drive is from a two-speed countershaft above the machine. The machine is equipped with two railheads and two sideheads. One railhead is shown swiveled to the left. The second is feeding a cutting tool to the left, planing a horizontal surface on a large casting. The sidehead to the right is feeding a cutting tool vertically downward.

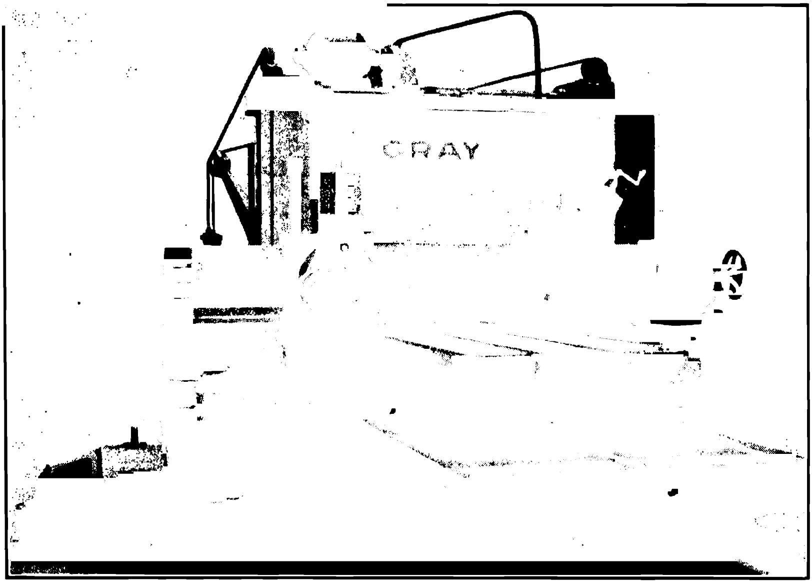
(*c*) A train of herringbone and spur gears combined, Fig. 6.

(*d*) The Sellers worm drive to the rack, or the Gray hypoid gear drive, Fig. 7.

(*e*) Hydraulic drive, Fig. 2. The table travel, as well as the tool feeds, is controlled by varying the quantity of oil pumped. This gives a very flexible and safe method of power transmission.

SPEEDS AND FEEDS

The rate at which the table is moved forward, forcing the work against the cutting tool, is called the cutting speed and is expressed in feet per minute. Modern planers permit cutting speeds from about 60 to 120 fpm. The return or noncutting stroke of the table is faster than the forward stroke in order that time may be saved. A return stroke of 2–3 times the forward stroke is usual.



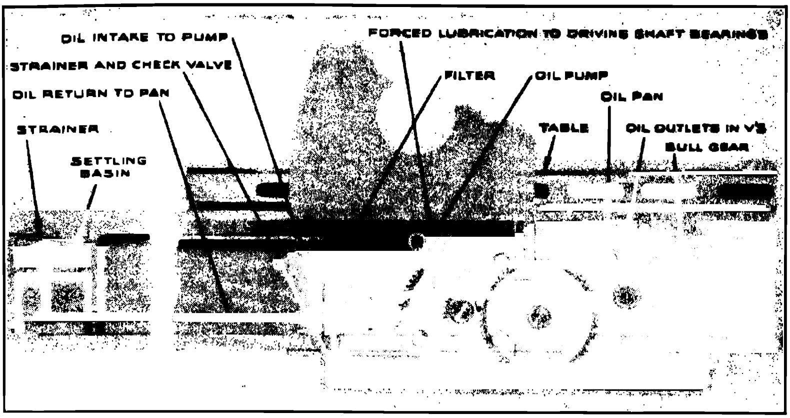
Courtesy The Gray Planer Co.

FIG. 4. A 54-in. by 42-in. by 20-ft. Gray Maximum-Service Planer, with Two Railheads and One Sidehead on Each Housing, Set Up to Machine Two Planer Rails.

The planer is equipped with a Reliance reversing motor and Cutler-Hammer control. The railhead to the right is swiveled to a 30-deg angle from the vertical and is equipped with a right-angle side-cutting tool for machining the angular surface of the planer rail. The railhead to the right is carrying a side-cutting tool and is being fed horizontally making an undercut. The reversing d-c drive motor is seen at the left.

The **length and position of travel** of the planer table are determined by the location of two trip dogs, Fig. 1, bolted to the slot in the side of the table, which actuate the belt-shifting device, cause the driving electric motor to reverse, or reverse the flow of oil in the hydraulic cylinder.

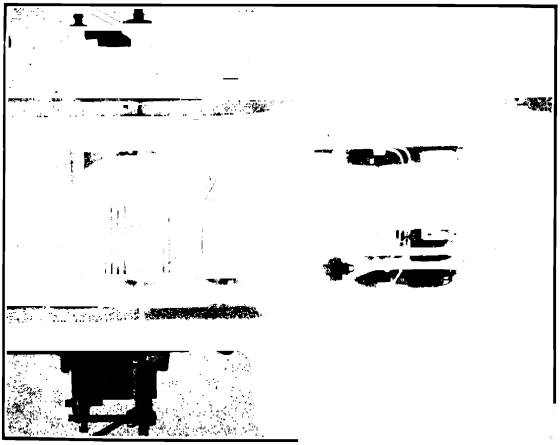
The cutting tool is held in a **tool post** or more often by straps and studs attached to a clapper hinged at its upper end to a clapper box or block; see Fig. 1. The block may be swiveled some 20 deg either side



Courtesy The G. A. Gray Co.

FIG. 5. Longitudinal Section through the Gray Planer Bed.

This shows the table drive gears from the pulley or motor shaft through three balanced helical-gear reductions to the large bull gear to the right, which engages the helical rack underneath the table. The oiling system, consisting of strainers, settling basins, and a filter, provides a flood of clean oil to the table ways, driving gears, and bearings. The double-acting oil pump is mounted on the outside of the planer bed, on the end of the first drive shaft, so as to pump oil whenever the planer runs in either direction.

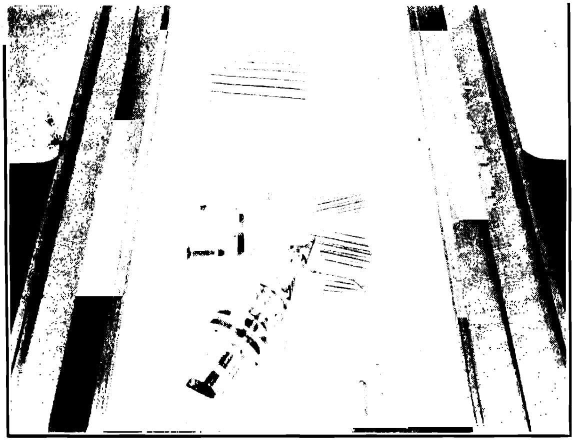


Courtesy The Giddings and Lewis Machine Tool Co.

FIG. 6. Plan View of the Cincinnati Planer Bed with Table Removed.

Showing the three herringbone-gear speed reductions and the single spur-gear reduction drive to the table. The driving-shaft gear is shown just below and to the left of the rectangular oil distribution tank, and the large spur bull gear which engages the rack under the table, to the left. The lubricating pump and oil-filter system which force-lubricates the ways and spray-lubricates the train of gears is shown.

of its central position to clear the work or to permit better adjustment of the tool, as illustrated in Fig. 4. The block is carried on a toolslide or ram which may be swiveled on a base or saddle. In Fig. 3 the left-hand railhead shows the clapper box swiveled on the toolslide and the slide swiveled to the left on the saddle. The saddle is gibbed to the horizontal crossrail which in turn is gibbed to the vertical housing. The saddle, toolslide, block, clapper, and straps constitute the railhead as shown assembled on the rail in Fig. 1. A similar head may be mounted on the column or housing, in which case it is called a sidehead. One side- and one railhead are shown in use in Fig. 3.



Courtesy G. A. Gray Co.

FIG. 7. The Latest " Space Saver " Drive on the Gray Planer.

View with table removed. The d-c, variable-speed, reversing motor drives the shaft terminating in the hypoid pinion. The drive is then through helical gears to the helical bull gear which engages the rack attached to the underside of the table.

The railhead as a complete unit may be fed by power to the right or left on the rail by means of the horizontal lead screw. The toolslide may be fed vertically up or down, or inclined, on the saddle by means of the toolslide feed screw driven by the hand crank on the upper end, as shown in Fig. 1, or by hand or power feed from either end of the rail through the horizontal splined feed rod. Sidehead tools also may be fed horizontally, vertically, or at an angle.

The amount of **feed** or movement of the tool, expressed in inches per stroke, may be adjusted at the right end of the rail, but the power feed may be engaged or disengaged at either end of the rail, as shown in Fig. 1. Usual feeds of the heads or toolslides range from $\frac{1}{64}$ in. to 1 in. per stroke by $\frac{1}{64}$-in. steps. Large feeds are used in finishing surfaces with a wide-nose end-cutting tool. Two or more heads may be mounted on the rail as shown in Fig. 3, but usually not more than one is mounted on each housing. When several heads are mounted on the rail, they may be given the same feed simultaneously, or one may be fed horizontally and another vertically, or at an angle, as shown in Fig. 4. Also, the railheads may be fed simultaneously with the sideheads in any combination of cuts, as shown in Fig. 3.

In the earlier planers, two cutting tools were arranged so that one cut was made on the forward stroke and a second cut on the reverse stroke. Equal forward and return table speeds were maintained. In the modern planer, the tools cut on the forward stroke and the table and work are quickly reversed. The tools are fed at the end of the return stroke. The clapper is raised on the return stroke if carbide tools are used.

The **reversing of the table** is accomplished in four different ways: by having an open- and crossed-belt drive in which the belts are alternately used as drivers; by having a reversing-type motor drive; by means of a crank as employed on shapers; and by reversing the flow of oil from a hydraulic pump.

When arranged for the open- and crossed-belt drive, the driving pulley consists of three parts--two outside freely rotating idler pulleys and one inside driving pulley attached to the driving shaft. This keyed driving pulley may be of one diameter, as shown in Fig. 1, or may have two diameters, as shown in Fig. 3. Two driving belts are provided, one crossed and one open. The crossed belt, giving a greater arc of contact on the pulley, is usually the belt to drive the table on the cutting stroke. During the cutting stroke, greater power is required and less speed. This belt, therefore, either drives to the pulley of larger diameter on the driving shaft, as shown in Fig. 3, or from the smaller pulley on the countershaft, as shown in Fig. 1. In Fig. 3, both driving belts are shown shifted to the outside idler pulleys and are running freely. The intermediate driving pulley, however, is stationary, and the planer table is not moving. To start the planer, the handle lever for table control on the side of the bed, indicated in Fig. 1, is forced upward or downward to shift one of the free-running belts onto the driving pulley. If the crossed belt, in Fig. 3, is forced onto the driving pulley, the planer table will move to the right on the cutting stroke. At the end of this stroke, the trip dog on the side of the planer table actuates the belt shifters so the crossed driving belt is shifted from the driving pulley to the loose pulley, and the open reversing belt is shifted from its loose pulley to the driving pulley. This causes the driving pulley to change its direction of rotation and, by virtue of different pulley diameters, return the table at a greater speed. At each end of the stroke, the two belts are shifted, one from its idler onto the driving pulley, and the other from the driving pulley onto its idler. This type of drive does not provide a positive length of stroke. The table travel will vary slightly in length for successive cuts because of the slippage of the shifting belts on the reversing pulley, so that proper allowances must be made. Power is transmitted from the drive shaft to the table by a train of gears. The last and largest gear of the train is called the bull gear and meshes with a rack attached to the underside of the table; see Figs. 5 and 6.

In cutting, the work passes the tool at the desired cutting speed expressed in feet per minute. Assuming that a flat surface is to be machined, such as shown by the tool on the railhead in Fig. 3, the tool point is set first to contact with the rough surface, and then withdrawn to the edge where it is adjusted to a position below the rough surface a distance equal to the thickness of the layer of metal to be removed. This distance, indicated directly on the feed dial, represents the depth of cut. The tool is then fed into the work, at the end of each noncutting stroke, parallel to the finished surface desired. To secure a good surface and accurate dimensions, two or more cuts are taken, the last of which is called the finishing cut.

SIZE

Planers are built in a wide variety of sizes as measured by the distance between the housings horizontally and between the rail and table vertically. Various lengths of table are optional. The Pond "timesaver," built by the Niles Tool Works Co., is made in sizes having capacities from 36 in. sq, requiring a 20- or 25-hp driving motor, to 72 in. sq, requiring a 35-hp driving motor. The Giddings and Lewis Machine Tool Co. manufactures the Cincinnati Hypro double housing planers having capacities from 30 in. sq to 120 in. sq, which require electric motors from 25 to 75 hp.

FEATURES

Spur **gear trains** to drive the table have been replaced by helical, herringbone, and worm gears to give smoother and more powerful drives. Forced and spray **lubrication** is used on all running shafts and gears. The oil is settled, strained, and filtered. Gears in sideheads, and those in the feed gearbox on the end of the rail, run in oil.

The length of the **bed** of the modern planer is twice the length of the table. Only a few years ago, the bed was made only one and one-half or one and two-thirds the length of the table. This caused the table to overhang on long strokes. Forced lubrication of the ways through openings shown in Fig. 6 have replaced the spring-supported spool running in oil, as shown in Fig. 1.

Power rapid traverse for positioning the toolheads and tools, rather than resorting to hand operation or to the slow mechanical feed, is provided on practically all modern planers. Power rapid traverse is furnished to the railheads by a separate motor usually mounted on the top of the housing. Motors mounted on the sideheads furnish power rapid traverse, as well as power feeds, to the sidehead tools. The rail itself is unclamped from the housing, elevated or lowered to any desirable point, and reclamped in its new position.

For the high-powered **drives,** the variable-speed direct-connected reversing motor is used almost universally. This type of drive lends the machine almost completely to push-button control.

Duplex or **dual control** is another feature emphasized on modern planers, in which the planer may be operated from either side of the bed. The overhanging pendant switch, Fig. 4, makes it possible to keep the push-button control constantly at the convenience of the operator. **Centralized control** is also a feature of modern planers. The operator, standing in a position to watch the cutting tool, conveniently controls all the functions of the planer.

PLANER EQUIPMENT AND ATTACHMENTS

Most of the attachments used in connection with planer work today are actually built into the planer as a part of it. The modern planer is so completely equipped with mechanical control that it can be operated with little physical effort.

A planer should be equipped with a heavy-duty vise similar to the two-screw type for shaper use. A wide assortment of types and sizes of holding clamps is necessary in order that the work may be attached to the table with little time loss, with little deflection of the workpiece, and with due regard for safety of the machine and operator. Angle plates of various sizes and shapes, step blocks, and parallels are useful in setting up work on a planer table. The planer table itself is provided with several T slots running the length of the table for holding T-headed bolts. Planer tables also are provided liberally with drilled and reamed holes for table stop pins with or without adjusting screws. The material to be machined should be clamped to the table in such a way that it is machined in an unstrained condition. If machined in a distorted position, the part will warp when the clamps are released. This danger is minimized if the clamps are released slightly before the final light finishing cut is taken.

QUESTIONS

1. What type of surfaces is the planer designed to machine?

2. Explain what is meant by cutting speed and its relation to the return stroke speed.

3. Explain the meaning of depth of cut and how it is obtained.

4. What is meant by feed and in what units is it expressed?

5. What are direct-reading dials?

6. What is meant by a clapper and what is its purpose?

7. What is the advantage of having the planer bed twice the length of the table?

8. What is meant by power rapid traverse and what is its advantage?

9. What are the five principal methods of classifying planers?

10. Name three different methods of applying power to the planer drive shaft.

11. What are the two principal means employed to secure the reciprocating action of a planer table?

12. Name several different methods of transmitting power from the drive shaft to the planer table.

13. To cut a groove 1 in. wide in the face of a large flat horizontal gray-iron casting, a square-ended tool 1 in. wide is being fed vertically into the piece $\frac{1}{16}$ in. at each stroke. What is the numerical value of the depth of cut and feed? How should this type of cut be designated?

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CHAPTER V

NOMENCLATURE AND MATERIALS FOR SINGLE-POINT TOOLS

SINGLE-POINT TOOLS FOR LATHES, PLANERS, AND SHAPERS

Lathes, planers, and shapers, as well as boring mills and turret lathes, are machine tools employing single-point tools. In general, the tools for these types of machines are similar in shape and material, except those producing special shapes or those meeting specific requirements. The fact that the planer and shaper utilize intermittent cuts, as against a continuous cut in the lathe, often makes it necessary that the tools for intermittent cutting be more rigid in themselves and in their mounting. It is not possible, however, to utilize the high speeds of continuous cutting in the planer and shaper because of the larger inertia forces set up in reversing the tools, or work, at the end of each stroke.

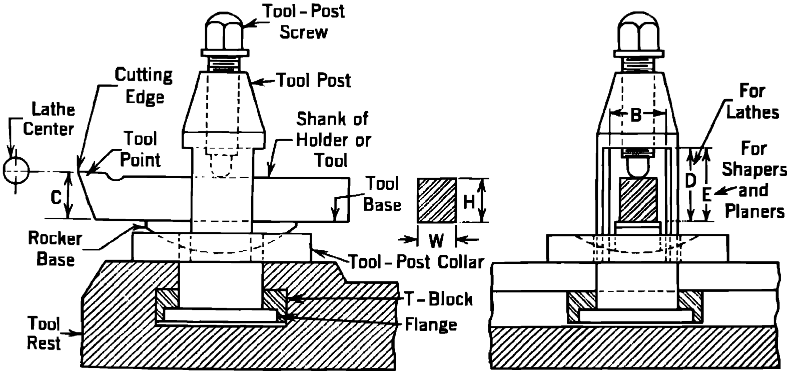


FIG. 1. A Single-Screw Tool Post with Rocker Base and Nomenclature as Used on Small Lathes.

The rocker base permits adjustment of the cutting edge to the centerline of the work by tilting the tool. A vertical adjustment only, by using shims, is preferred as the tool is mounted more rigidly and change of relief and rake angles is prevented.

Tool Posts

Single-point tools are held rigidly in a machine tool by being clamped in a tool post. The single-screw tool post, Fig. 1, is common on the smaller lathes and shapers, ASA B5.2, 1948. The rocker base is convenient for tilting the tool to adjust the cutting edge to the center height of the work. This procedure changes the rake and relief angles, and it is better practice to use a fixed-bed tool post and adjust for height by the use of shims under the tool. Planers and large shapers and lathes use strap and stud toolholders more commonly, Fig. IV-1, while the single open-side. Fig. XI-17, or 4-way turret tool posts, Fig. XI-4, are also often used on large lathes, boring mills, and turret lathes.

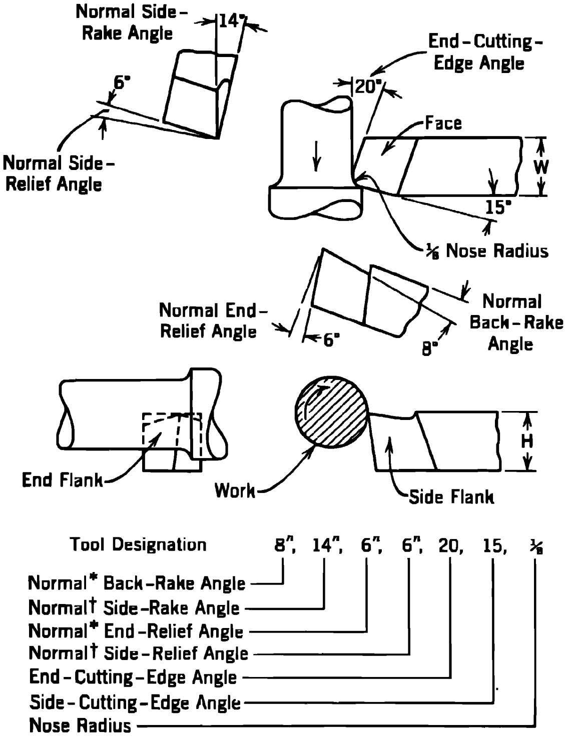


FIG. 2. A Typical Straight-Shank, Right-Cut, RC-S, Solid Tool of High Speed Steel, Ground for Turning Steel of about 250–300 Brinell.

Rake and relief angles are shown as normal to cutting edges.
* Normal to end-cutting edge.
† Normal to side-cutting edge.

TOOL NOMENCLATURE AND TYPES OF CUTTING TOOLS AND HOLDERS

Tool Nomenclature

A typical straight-cutting-edge tool of the shank type for lathe, planer, and shaper as ground on the hardened end of rectangular or square bar stock is shown in Fig. 2. Each tool consists of a **shank** and **point.** In some cases, as in deep-hole boring tools, the point is connected to the shank by a reduced section known as the **neck.**

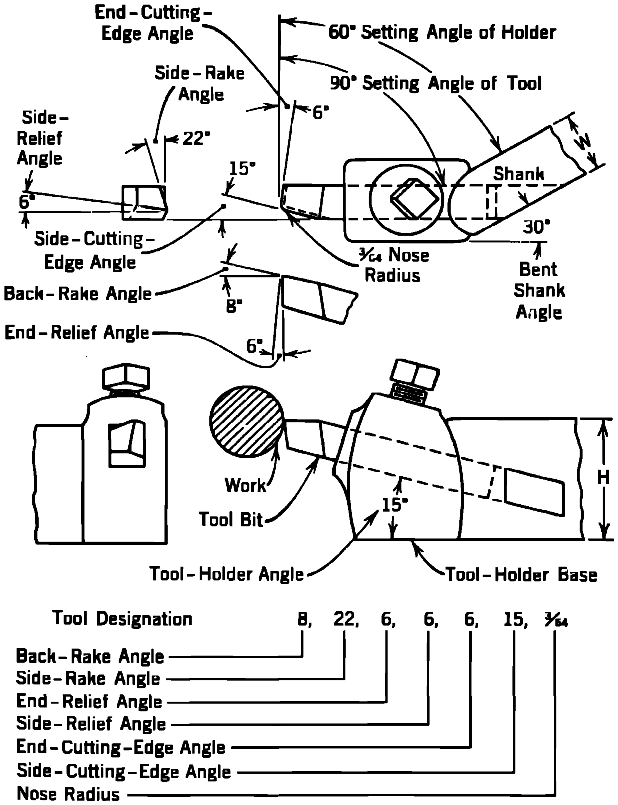


Fig. 3. A Typical Toolholder with 30-deg Left-Bent Shank and 15-deg Toolholder Angle; a Right-Cut Tool Bit Suitable for Turning Soft Steel Is Shown.

Rake and relief angles are shown based on centerline of toolholder head. Common sizes in inches are:

5/16 × 7/8 × 5 holder for 1/4 square × 2 1/2 long bits.
1/2 × 1 1/8 × 6 " " 5/16 " × 2 1/2 " "
5/8 × 1 3/8 × 7 " " 3/8 " × 3 " "
3/4 × 1 5/8 × 8 " " 1/2 " × 4 " "

For heavy-duty turning the tool should have a shank, say, 1 × 1 × 7 in. long or 5/8 in. wide, 1 1/4 in. deep, and 8 in. long, according to the American Standard ASA B5.22, 1950, which gives all standard sizes for square- and rectangular-shank tools and holders. Figure 2 shows a straight-shank, right-cut, solid tool of high speed steel with the rake and relief angles indicated as normal in relation to the side- and end-cutting edges. Figure 3 shows a commercial bent-shank toolholder with a 15-deg toolholder angle for a high speed steel bit. Holders for cast nonferrous metal bits and solid or tipped sintered-carbide bits have a toolholder angle of 0 deg. Four standard sizes of holders and bits are indicated.

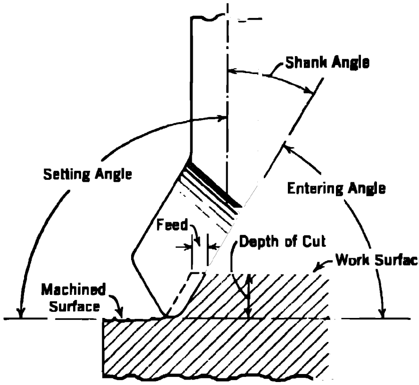


FIG. 4. Right-Cut, Left-Bent-Shank Tool; Symbol RC(LB).

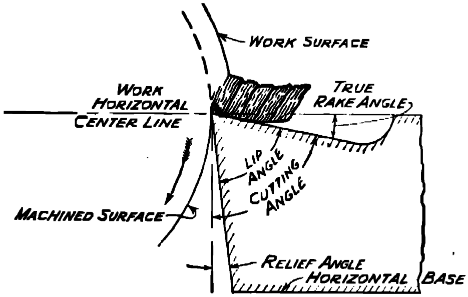


FIG. 5. A Section through the Plane of the Chip Flow.

The **profile** is a plan view when looking at the face from a point at right angles to the base. Those angles between the tool and work which depend not only on the shape of the tool but also on its position with respect to the work are called **working angles**, Fig. 3. The **setting angle** is the angle made by the straight portion of the shank of the tool with the **machined surface** of the work. The **entering angle** is the angle which the side-cutting edge makes with the **work surface**, i.e., the surface to be machined, Fig. 4. The **true rake** is the actual slope of the tool face from the cutting edge in the direction of chip flow, as shown in Fig. 5. A tool will have different values of true rake for each combination of depth of cut and feed, inasmuch as the direction of flow of the chip changes with these combinations (see Fig. VII-8).

CLASSES OF SINGLE-POINT TOOLS

Single-point tools are classified according to their shape, construction, or use as follows: solid; tipped; raised face or forged; toolholder and tool bits; radial; tangential; circular; straight; bent; offset; gooseneck; right cut, left cut, or end cut; roughing or finishing; curved or straight cutting edge; square nose; cut off or parting; side facing; dovetailed; intermittent cutting; boring, threading, and recessing; knurling; radius; form; and skiving. A variety of classes of forged tools is illustrated in Fig. 6, and some ground tools with typical angles are shown in Figs. 2, 3, and 7. The American Standard types of carbide-tipped tools, styles A–G, incl., are shown in Figs. 19–25, incl. Styles A and B have 0-deg and 15-deg side-cutting-edge angles, respectively; C, Fig. 21, has a square point; D, Fig. 22, has an 80-deg nose angle; E, Fig. 23, has a sharp 60-deg nose angle for threading;

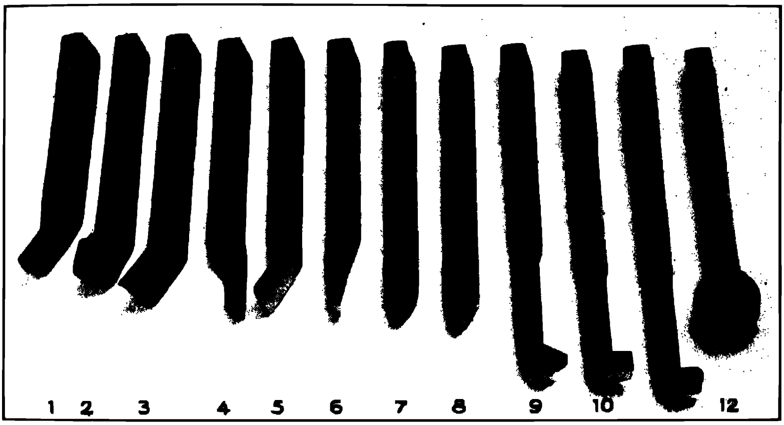
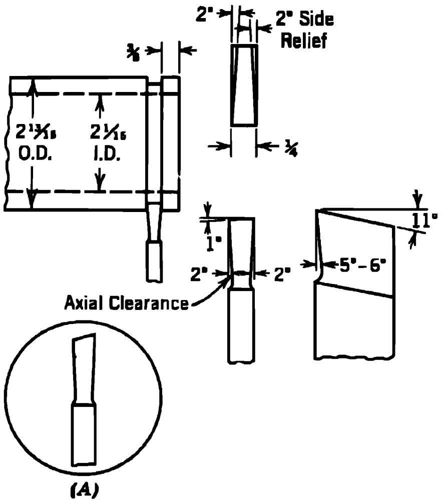


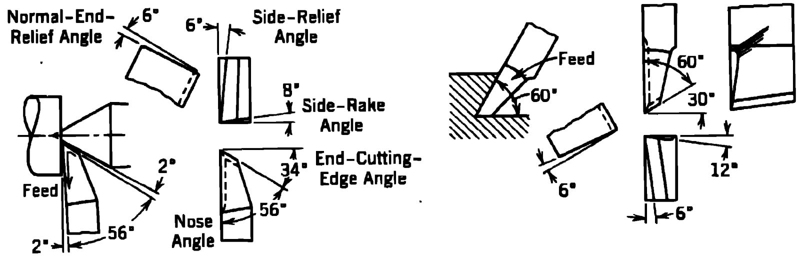
Fig. 6. A Selected Set of Forged Shank-Type Tools.

1. Right-cut, 30-deg, left-bent-shank, roughing tool for general purposes, Fig. 4.
2. Left-cut, left-offset, heavy-duty, roughing tool.
3. End-cut, 30-deg, left-bent-shank, finish-turning tool.
4. Right-cut, straight-shank, finish-facing tool.
5. Right-cut, 30-deg, left-bent-shank, finish-facing tool.
6. Right-cut, straight-shank, worm and Acme thread cutting tool.
7. Left-cut, straight-shank, worm and Acme thread cutting tool.
8. Right-cut, straight-shank, V and National Standard thread cutting tool.
9. Inside left-cut, straight-shank, V and National Standard thread cutting tool.
10. Straight-shank, inside finishing tool.
11. Straight-shank, rough-boring tool.
12. Straight-shank, radius-forming tool.



A. A Cut-off (or Parting Tool).

This is an end-cut tool with side-cutting edges and side axial clearance. The insert (*A*) shows the end-cutting edge beveled so as to leave no burr on the piece cut off from a solid bar.



(*B*) (*C*)

FIG. 7. Cut-off (*A*), Side Facing (*B*), and Dovetailing (*C*) Tools.

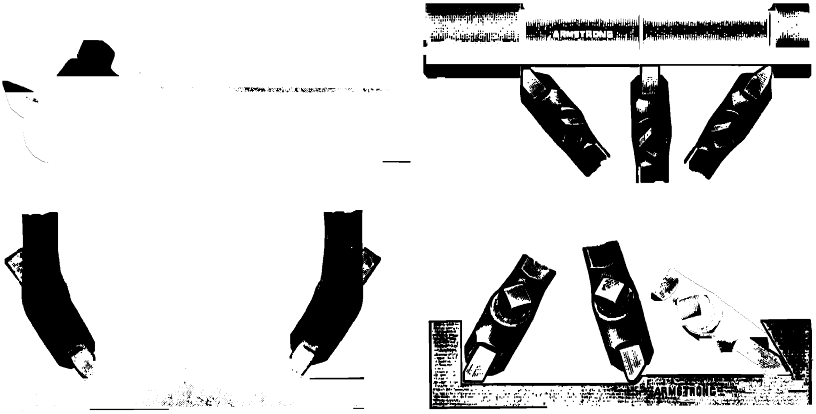
F, Fig. 24, is an offset end-cutting tool; and G, Fig. 25, is an offset side-cutting tool.

Solid or Shank Type, Tipped, and Bit Tools

The point of a single-point tool may be:

1. Formed by **grinding** on the end of a shank of hardened tool steel, Fig. 2.
2. **Forged** on the end of a shank and subsequently hardened and ground, Figs. 4 and 6.
3. A **bit** or small portion of cutting-tool material of square, rectangular, or other section, or forged to special shape, clamped in the end of a holder or shank, Figs. 3 and 8–17. The angle of inclination of the bit from the base of the holder is known as the **toolholder angle.** Shanks and holders may be bent left or right, Figs. 3 and 4, or offset, Figs. 24 and 25.
4. A **tip** is an insert of the cutting-tool material to form the cutting edge and face, Figs. 17, 18, and 19.

When forging and heat-treating facilities are available, sets of **forged tools** covering a variety of shapes and sizes can be made quickly and cheaply, Fig. 6. Complete sets of tools, standardized as to size and shape for special jobs, may be made and kept on hand in conveniently located tool cribs for issue. Unless such standardization is employed, each operator or foreman is likely to accumulate sets of his own which may cover an unnecessarily large assortment of shapes and sizes and lead to duplication.



Courtesy Armstrong Brothers Tool Co.

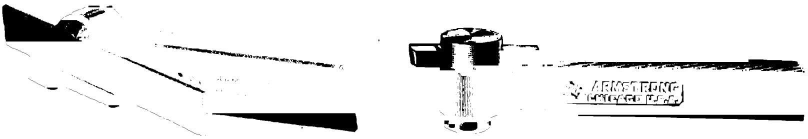
FIG. 8. Forged Toolholders for Square Section Bits.

The bit is held in place by the screw. Holders are furnished for bits from $\frac{3}{16}$ in. to $1\frac{1}{8}$ in. sq. Tool bits may be ground to convenient shapes to suit the nature of the work. These tools may be used for lathe or shaper work or for roughing and finishing, as illustrated. They also are furnished straight, as at upper left, and with right- and left-bent shank, as at lower left.

Tool bits and toolholders: Tool bits are pieces of the cutting-tool material of square, rectangular, or formed sections usually purchased ready for grinding to shape and use. They may be held by some form of clamping in **toolholders** usually made of forgings of strong tough steel. Relatively cheap holders will serve for a long period of time, and the bits can be replaced as they are used up.

A variety of types of holders for tool bits or cutters of various shapes and sizes is shown in Figs. 8–17, incl. These holders are designed to accommodate a wide variety of shapes of bits for specific purposes, although they may be used on various production jobs employing a single shape of bit. Figure 8 shows the most common type of holder in toolroom use.

Little grinding is necessary to prepare the tool for specific purposes. The bit is held in the holder at a convenient slope. The overhang of the toolholder beyond its support should be kept as low as possible to maintain rigidity. Likewise the tool bit should project from the holder only about one and one-half times the tool-bit width, sufficient to provide chip clearance but not enough to permit chatter or breakage.



Courtesy Armstrong Brothers Tool Co.

A. Left-Bent Holders for Cutting-Off and Side-Cutting Tool Bits.

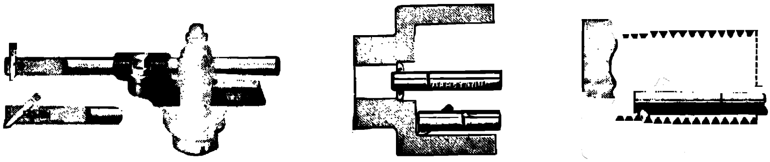
Holders clamp by cam action. The cutting-off and side-cutting blades are interchangeable.

Courtesy Armstrong Brothers Tool Co.

B. Planer or Shaper Toolholder and Bit.

The face of the bit is held parallel to the base of the holder to prevent digging in. The bit may be swiveled to any position.

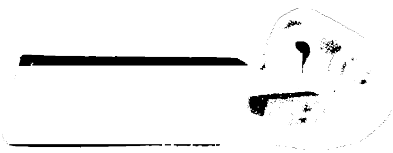
Fig. 9. Toolholders and Bits.



Courtesy Armstrong Brothers Tool Co.

Fig. 10. Boring Bars and Shank Holder for Lathe Tool Posts.

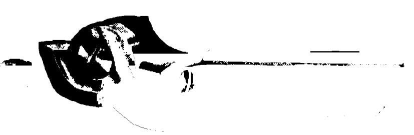
A half turn of the screw clamps or releases the bar in any position in the holder. The cutters are standard stock bits and are held in straight or angular position by the threaded sleeve on the end of the bar. The cut in the center shows a double-ended cutter roughing out the central cored hole and an angular cutter used for boring and facing. The cut to the right shows the bit ground for cutting an internal thread.



Courtesy J. H. Williams and Co.

Fig. 11. Threading Toolholders with Spring or Lockable Head.

Used as a spring tool for finishing, but with nut (not shown) in lower hole the bit has rigid backing required for coarse threading or heavy turning cuts.

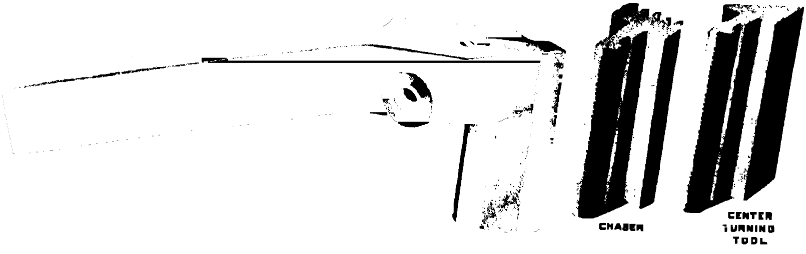


Courtesy Armstrong Brothers Tool Co.

Fig. 12. A Thread-Cutting Tool.

This tool consists of a holder and a circular formed threading cutter. As the bit is resharpened, it is rotated on its axis by the adjusting screw to keep the face in a horizontal plane through the axis of the work.

The cutoff or side-cutting blades used in the holder, Fig. 9*A*, are also of a formed section to provide side relief, so as to require the minimum amount of grinding. The bits used in the planing toolholder, Fig. 9*B*, are square or rectangular in section and are interchangeable with the turning toolholder, Fig. 8, the boring bars, Fig. 10, and the threading toolholder, Fig. 11.

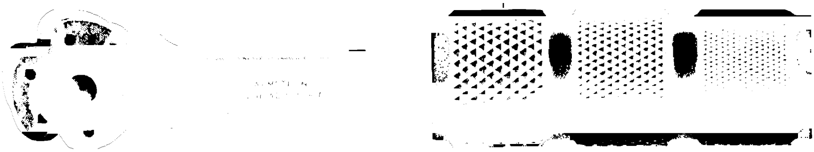


Courtesy Pratt and Whitney Co.

FIG. 13. Left-Bent Shank Threading Toolholder of the Rigid Type Containing a Single-Point Tangential-Type Formed Cutter.

Only the face of the cutter is ground off to resharpen. The cutters are placed with a relief angle of 15 deg, and if, in sharpening, this angle is maintained there will be no change in the form of the thread which the tool cuts. The bit or tool is secured in the holder by a clamp operated by the knurled nut. The bit is adjusted in the holder for height by loosening the clamp and turning the elevating screw. The thread-chaser bit and a center-turning tool bit are interchangeable with the single-point bit.

The toolholders shown in Figs. 11, 12, and 13 are used principally for thread cutting. That shown in Fig. 11 may be used with a springhead or with the head locked to form a rigid holder. In light finishing cuts, such as those taken for finishing threads, a better finish is sometimes obtained with the spring-type tool, but rigidity is required when heavy cuts are taken. The thread-cutting tools, represented in Figs. 12 and 13, use tool bits of the formed type, so that as the tool becomes dull, only the face has to be ground, and the bit adjusted on the holder for the proper height. The holder, illustrated in Fig. 15, shows a clever method of adapting a formed tool bit to production turning. The bits are furnished hardened and



Courtesy Armstrong Brothers Tool Co.

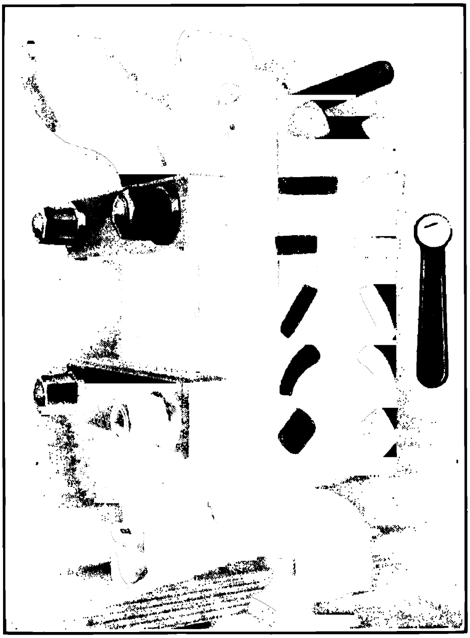
FIG. 14. Knurling Toolholder and Diamond-Pattern Knurls.

The universal revolving head contains three pairs of knurls, giving a coarse 14-pitch, medium 21-pitch, and fine 33-pitch finish, as shown by the specimen.

Courtesy The Ready Tool Co.

Fig. 15. Holder Style R and Roughing Tool Bit of the Formed Tangential Type.

The profile is patterned after F. W. Taylor's sharp tools. The bit is sharpened by grinding the top face only to the appropriate rake angles. Relief angles and profile are automatically maintained.

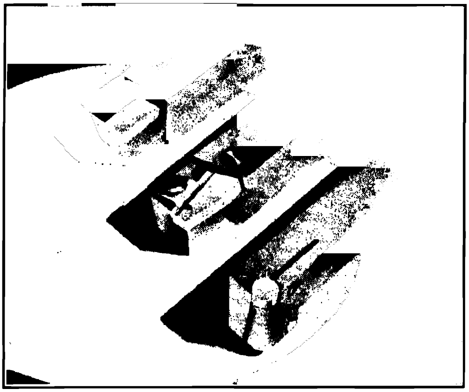


Courtesy O K Tool Co.

Fig. 16. Planer Tool-Bit Holder, One End Straight Style and the Other End Gooseneck, with a Standard Assortment of Twelve Planer Tool Bits.

The wrench for binding the tip in the holder and a hand grinding holder are shown. The tips are forged from high speed steel, heat-treated and ground. Two holders are held by straps in a planer head. The straight-ended holder to the left is carrying a curved-cutting-edge, heavy-duty roughing tool; the gooseneck holder to the right contains a straight-edge finishing tool. Rough and finish cuts are being made simultaneously.

ground with a definite profile and may be adjusted positively for height in the holder.



Courtesy Kennametal Inc.

FIG. 17. Various Types of Carbide-Tipped Single-Point Tools — Recessed and Brazed Tip at the Left, a Clamped-On Tip Adjusted by Back-Up Screw in the Center, and a Solid Cylinder Bit of any Given Radius at the Right.

Holders similar to that on the right are available for triangular, square, and rectangular bits, and all may have chip breakers ground in the face.

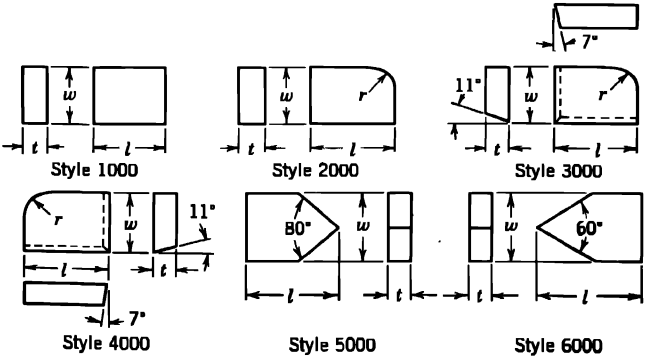


FIG. 18. Six ASA Standard Shapes of Sintered-Carbide Tips.

Each is available in a wide variety of sizes. Many other tips for reaming as well as the tangential, cylindrical, triangular, and square bits or inserts are standardized.

Figure 16 shows a type of holder which employs die-forged tool bits. Bits of various shapes are interchangeable, so that these holders may be used with a single form of bit for production work or with a variety of shapes for more general work. Two holders are being used simultaneously. One supports a round-nose roughing bit which is taking a roughing cut while the second toolholder supports a broad-nose finishing bit, so that a surface may be roughed and finished at one traverse of the planer head across the work. It is better practice to take the light finishing cut with a larger feed after all roughing cuts are completed, however.

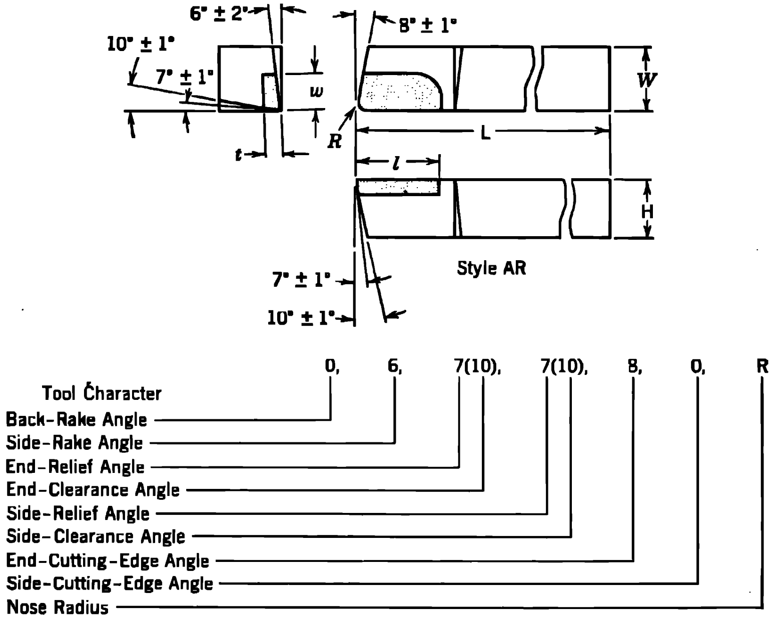


FIG. 19. ASA Sintered-Carbide-Tipped Tool, Style A.

A right-cut, carbide-tipped, single-point tool, style A, with 0-deg side-cutting-edge angle and with tool character of suggested angles referred to the shank. Tool AR16 has a shank ($W \times H \times L$)1 × 1 × 7 in. and a tip ($t \times w \times l$) ¼ × 9⁄16 × 1 in.

Tipped tools: To save the more expensive cutting-tool materials, small pieces are often brazed, welded, or clamped to the end of a heavy shank, Fig. 17. The materials used as tips may be high speed and cobalt high speed steel, cast nonferrous metal, the carbides, and diamonds. Each material requires its own method of welding or brazing to the tool shank, as explained under cutting-tool materials. The tipped tools give the general appearance of being ordinary tools of the shank type. Sintered-carbide tips are made in six standard shapes shown in Fig. 18, and each is available in a wide range of sizes. Figure 19 shows sintered-carbide bits brazed to steel shanks. The tip is generally made to fit a recess in the shank on one or two sides as shown, so as to relieve the brazing material of the cutting forces. Tips may be brazed on the flat face, however, and thus reduce tip cracking due to thermal stresses.

A piece of cast nonferrous metal welded to a chromium-nickel steel shank is shown in Fig. VII-5.

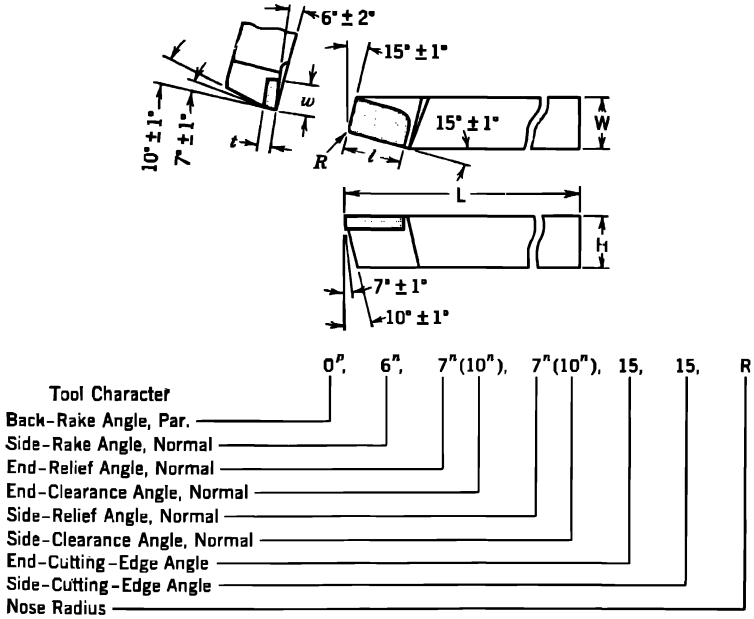


FIG. 20. ASA Sintered-Carbide-Tipped Tool, Style B.

A right-cut, tipped, single-point tool, style B, with 15-deg side-cutting-edge angle and tool character in which angles are referred to as normal to the cutting edge. (The normal angles are often used in tool grinding.)

CUTTING-TOOL MATERIALS

A wide variety of materials is used in making up cutting tools. This variety is necessary to meet the many conditions imposed upon the cutting tool, such as machining various types of materials and taking heavy and light cuts. Those materials used in making up cutting tools for lathes, planers, and shapers may be outlined as follows:

1. Plain high-carbon tool steels.
2. Low-alloy carbon tool steels.
3. Semihigh speed or finishing steels.
4. High speed steels of the tungsten or molybdenum type.

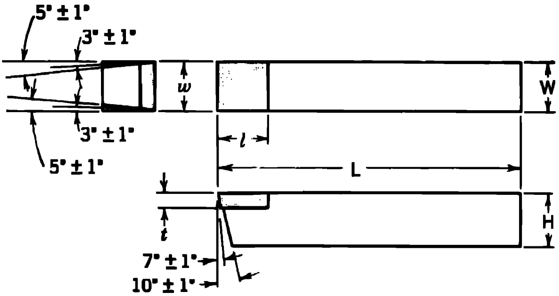


FIG. 21. ASA Sintered-Carbide-Tipped Tool, Style C.

A square-end or end-cutting, tipped tool. Tool character, 0, 0, 7 (10), 3 (5) R, 3 (5) L, 0, 0, sq.

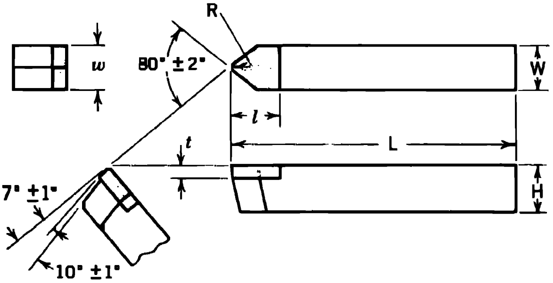


FIG. 22. ASA Sintered-Carbide-Tipped Tool, Style D.

An 80-deg nose-angle, tipped tool. Tool character, 0, 0, 7^n (10^n) R, 7^n (10^n) L, 50, 50, R.

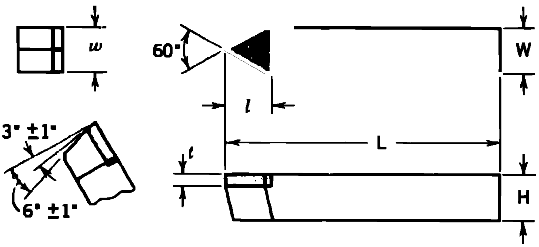


FIG. 23. ASA Sintered-Carbide-Tipped Tool, Style E.

A tipped threading tool with a 60-deg nose angle. Tool character, 0, 0, 3^n (6^n) R, 3^n (6^n) L, 60, 60, 0.

5. Cobalt high speed steels.
6. Nonferrous alloys consisting principally of cobalt, chromium, and tungsten, such as Stellite.
7. Sintered carbides.
8. Diamonds and sapphires.
9. Ceramics.

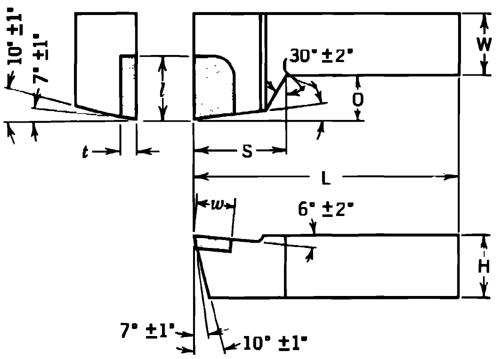


FIG. 24. ASA Sintered-Carbide-Tipped Tool, Style F.

An offset, end-cutting, single-point tipped tool. Tool character, 6, 0, 7 (10), 7 (10), 0, −30, R.

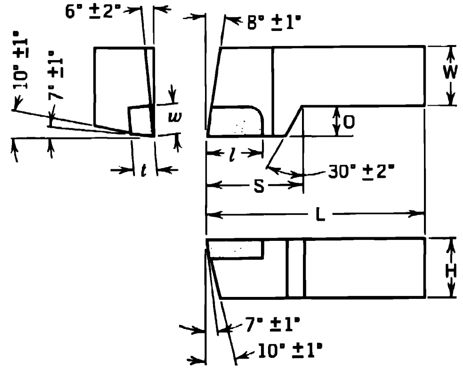


FIG. 25. ASA Sintered-Carbide-Tipped Tool, Style G.

An offset, side-cutting, single-point tipped tool. Tool character, 0, 6, 7 (10), 7 (10), 8, 0, R.

Tool Quality

The quality of tool-steel tools depends upon several factors, such as the chemical analysis, the method of manufacture, the heat treatment, the shape, and the final grinding. The first three factors vary considerably among the manufacturers of tool steel, and the requirements of users vary as to the composition of steel for specific work. Cutting-tool steels may be purchased in accordance with definite specifications, in which case the buyer is responsible for the results, or the steel may be purchased for a given purpose, leaving the specifications up to the manufacturer, who in turn is responsible for the results produced.

Carbon Tool Steel

Carbon tool steel, No. 1, Table 1, costing from 16 to 20 cents per lb, may be made into tools of all types. Hardened high-carbon tool steel possesses a high degree of hardness and toughness. It is used for all types of cutting tools for light-duty work. It cannot withstand cuts producing temperatures above 400° F. As keen cutting edges are obtainable, it is often used in production work in cutting free-machining steel or brass, where temperatures are kept down by a copious supply of coolant. Because of its low price, a great assortment of carbon tool-steel tools of a variety of sizes and forms, Fig. 6, may be kept on hand for occasional use, with small total investment. These tools will render satisfactory service, particularly when the actual cutting time of each is small. When the cutting time is large and tool life or endurance becomes a factor, carbon tool steel is replaced by more productive tool materials.

Lathe, planer, and shaper tools of the plain-carbon-steel type usually contain from 1.00 to 1.30 per cent carbon. Drills, taps, threading dies, and milling cutters may average from 0.90 to 1.20 per cent carbon (see 1, Table XVI-1). Vanadium up to 0.15 per cent is added to increase the toughness of the steel. Chromium up to about 0.50 per cent may be added to increase the depth of hardness (see 2, Table XVI-1).

Heat treatment of plain carbon tool steel: It is good practice to refer to the literature of the manufacturer of the steel for specific heat treatments because of the wide variety of analyses. Average practice is as follows:

To **normalize** before hardening, after machining or forging, to eliminate stresses and obtain a uniform grain structure, heat slowly and uniformly in the furnace at the rate of ¾–1 hr per in. of thickness, to 1,550–1,700° F, and hold for one-half the heating time to obtain complete penetration of heat and for complete refinement of grain. Remove from the furnace and cool in air. The higher temperatures are for the higher-carbon steels.

The purpose of **annealing** is to soften the steel and obtain desired structures for hardening or machining. Heat the steel slowly and uniformly to 1,400–1,440° F and hold 1–4 hr until a complete penetration of heat is obtained. Cool slowly (not to exceed 50° F per hr) to 1,000° F, either in the furnace or buried in an insulating material such as lime or ashes, after which more rapid cooling may be used. The higher temperatures are for the higher-carbon range.

To **harden**, heat the steel uniformly to a temperature of 1,450–1,500° F for the lower-carbon range, and 1,400–1,475° F for the higher range. Quench in water or preferably a brine solution of 10 per cent by weight held at a temperature of 70–80° F, but remove the tool before it has cooled to about 200° F. Oil may be used for quenching thin sections. The higher temperatures are for the lower-carbon range. A semimuffle or muffle furnace may be used, but often lead or salt baths are advantageous. The latter require a slightly higher temperature, owing to the more rapid transfer of heat.

Temper to relieve strains and reduce brittleness by reheating the tool uniformly to 300–550° F while it is still warm. Hold for 1 hr and cool in still air.

To **forge** to shape, or refine the grain structure, heat uniformly to 1,800–2,000° F. The higher temperatures are for larger sections or rapid reductions. Forge constantly but not below a temperature of 1,500° F (see *Metals Handbook,* 1948 Ed., p. 660).

Semihigh Speed Steel

Semihigh speed steel, costing from 30 to 50 cents per lb, is used where there is severe wear but little heat generated, as in blanking and forming dies or in finishing tools like reamers. It has but 1½–4 per cent tungsten, so cannot be classed with high speed steel. Tools of this material, when properly heat treated, maintain keen cutting edges. They cannot be run at any higher speeds, feeds, etc., than can plain carbon tool steels and moreover do not possess any great toughness, owing to increased hardness penetration. Steels of this type are made in a wide variety of compositions.

High Speed Steel

High speed steel, costing from 75 cents up per lb in large quantities of bar stock, or about $2.00 per lb in tool-bit form, is used for heavy or high-speed cuts where tool endurance is of importance. It performs to advantage in nearly every type of job on ferrous or nonferrous metals, or on difficult nonmetallic materials such as Bakelite, hard rubber, fiber, cardboard, or asbestos.

High speed steel, introduced in 1900 by Taylor and White, has a high degree of hardness at all temperatures up to 1,100° F. It is capable of removing a chip at a cutting speed from two to three times that of carbon-steel tools and will last for a longer period of time per grind, resulting in seven to ten times the output. It is good practice, however, while cutting, to flood the high speed steel tool with a copious supply of cutting fluid so as to keep the tool below a red heat. It will lose its hardness at the higher temperatures and fail more quickly.

Most high speed steel metal-cutting tools in use today are made from steel of the 18–4–1 type (18 per cent tungsten, 4 per cent chromium, and 1 per cent vanadium), 2, Table 1. This type of high speed steel is the simplest to harden of all the different high speed steels, as it has about a 100° tolerance on the quenching temperature. There continues to be a slight demand for the so-called low-tungsten high-vanadium type of high speed steel containing about 14 per cent tungsten and 2 per cent vanadium, 3, Table 1. The 18W–4Cr–2Va and the 18W–4Cr–3¼Va steels, 4, Table 1, give increased red hardness, toughness, and abrasion resistance required for machining very hard steels where slightly higher costs over the 18–4–1 steel are warranted by better performance.

Cobalt is added to high speed steels to increase red hardness to give the 14W–4Cr–2Va–5Co, 18W–4Cr–1Va–4Co, 18W–4Cr–2Va–7Co, and 20W–4Cr–1½Va–12 Co, 5–8, Table 1, types of high speed steel. Cobalt steels, introduced in 1928 as superhigh speed steels, cost approximately $2.50 per lb and are commonly used as tips or bits. Unless hardened in salt baths or controlled nonoxidizing atmospheres, they harden with a soft skin and must be ground all over after treating.

Molybdenum high speed steels are now developed in which the tungsten is replaced wholly or partially by molybdenum. The most widely used one is the Mo-Max type 9, Table 1 (8Mo–1½W–4Cr–1Va), a general-purpose material with performance characteristics comparable with those of 18–4–1 and 18–4–2 tungsten steels. The second type of molybdenum steel (8Mo–4Cr–2Va), containing no tungsten, is found to be of uniform quality, and is comparable in performance with the 18–4–1 type. There are other molybdenum high speed steels now marketed, having various tungsten-molybdenum ratios, with or without cobalt, or with variations in percentages of the minor alloys, chromium, and vanadium, as indicated by 9–13, Table 1.

Heat treatment of high speed steel: After forging and machining high speed steel should be **annealed** before it is hardened. To avoid oxidation and scaling, the tool should be packed in annealing boxes in cast-iron chips, fine sand, lime, ashes, mica, etc. Covers should be sealed airtight with fire clay and the annealing boxes charged into the furnace and heated slowly and uniformly to a temperature of

TABLE 1. CHEMICAL ANALYSIS AND USE OF METALS USED IN CUTTING TOOLS*

No.	Class	Chemical Analysis, per cent											Properties and Use*
		C	Si	Mn	P	S	Co	Cr	V	W	Mo	Fe	
1	Carbon tool steel (water hardening)	1.10 1.20	0.30 Max.	0.30 Max.	0.03 Max.	0.03 Max.						Bal.	All types of cutting tools for light duty. High degree of hardness and toughness.
2	H.s.s. (18–4–1)	0.55 0.75	0.32	0.20	0.011	0.009		4.0	1.00	18.0		Bal.	High speed steel tools retain hardness at high temperatures. Used for tools for general roughing and finishing work on all types of materials. Air or oil hardening. Best general-purpose.
3	H.s.s. (14–4–2) (low W, high Va)	0.66	0.42	0.32	0.029	0.025		4.0	2.00	14.0		Bal.	
4	H.s.s. (18–4–2) (high W, high Va) and (18–4–3¼)	0.75 0.85	0.32	0.32	0.02	0.014		4.0	2.00 3¼	18.0	0.40 0.90	Bal.	
5	H.s.s. (Co) (14–4–2–5)	0.70	0.25	0.15	0.02	0.02	5.00 8.00	4.0	2.00	13.0		Bal.	Tough. Used as heavy-duty tools, hard steel, hard spots in iron or steel castings, scale, etc.
6	H.s.s. (Co) (18–4–1–4)	0.65 0.80	0.15	0.41	0.021	0.008	3.00 5.00	4.0	1.00	18.5	0.18	Bal.	
7	H.s.s. (Co) (18–4–2–8)	0.70					6.0 9.0	4.0	1.90	18.0	0.75	Bal.	Strong, tough, and high red hardness.
8	H.s.s. (Co) (20–4–1.5–12)	0.70					10.0 13.0	4.0	2.00	19.0	0.75	Bal.	For heavy cuts in hard materials.
9	H.s.s. (Mo-Max) (8–1½–4–1)	0.70 0.85						4.0	0.90 1.50	1.25 2.00	8.00 9.50	Bal.	About equal to 18–4–1.
10	H.s.s. (Mo) (8–4–2)	0.70 0.90						4.0	1.50 2.25		7.50 9.00	Bal.	About equal to 18–4–1.
11	H.s.s. (Mo-Max, Co) (8Mo-1.5W-4Cr-1V-4 Co)	0.70 0.90					4.00	4.0	1.00	1.5	8.00	Bal.	About equal to 18–4–1–4.
12	H.s.s. (Mo, Co) (8Mo-4Cr-1Va-5 Co)	0.75 0.90					4.50 5.50	4.0	1.05 1.35		8.00 9.00	Bal.	Contains 1 per cent Boron.
13	H.s.s. (W-Mo) (6W-5Mo-4Cr-1½Va)	0.75 0.90						4.0	1.25 2.00	6.0	5.00	Bal.	About equal to 18–4–1.
14	Cast nonferrous	2.15 2.45					43.0 48.0	30.0 35.0		15.0 17.0			Hard and abrasive-resistant, but brittle. For cutting cast iron.
15	Sintered carbide (WC)	5.68					6.1			87.4			Very hard and brittle. Used to cut abrasive and very hard materials.

Note: Oil-hardening and die steels are given in Table XVI-1.
* See Refs. 1 and 2 and "Comparative Tool Steel Brands," *The Iron Age*, July 29, 1948, p. 79.

1,600–1,650° F. They should be allowed to soak at this temperature for 1–4 hr, till thoroughly heated, and then cooled slowly (about 30° per hr) to 1,000° F in the furnace before being unpacked, after which cooling may be more rapid. Resultant hardness should be 212–218 Bhn. Large, intricate tools may be heated to approximately 1,000° F in a first preheat. After machining and before hardening, it may be necessary to relieve harmful machining strains by annealing at 1,200–1,350° F. If oxidation and scaling are not injurious to the tool, open-furnace annealing is permissible, but both the heating and cooling must be slow and uniform.

To **harden,** high speed steel is **preheated** slowly and uniformly to 1,550° F. For large tools, or where distortion is to be avoided, it is often advisable to use two preheating furnaces, one held at 1,100–1,200° F, and the other at 1,450–1,600° F. To **heat for quenching,** transfer the preheated tool quickly to a high-heat furnace or salt bath maintained at 2,250–2,400° F for 18–4–1 and 18–4–2 types of steel, and hold at this high heat for a time sufficient for proper solution of the carbides without an excessive grain growth or damage to the surface. For small tools, 2 min is sufficient; for tools 1 in. and up, 4–5 min is required. The tools are quenched in oil, air, or a molten salt bath, the latter at approximately 1,100° F. From the oil or bath quench, the tool is cooled slowly to 200–300° F. It is then reheated slowly and uniformly to 1,025–1,150° F, held for 1–4 hr, and then air cooled for **tempering.** Two and sometimes three tempering cycles are necessary to complete the transformation of austenite to martensite, and the internal stresses are relieved. The transformation is continued to a small degree by adding a cold quench to −100° F or lower. Considerable evidence indicates that subzero treatment of a high speed steel tool does not improve the tool's performance in any way to a greater extent than does double tempering. Hardnesses of 62–68 Rockwell C are desired. The lower values are preferred for tools requiring toughness.

Each of the several types of high speed steel must be given its own individual type of heat treatment in order to secure its best performance. The 14–4–2 steel is quenched from 2,200–2,300° F, the Mo-Max type from 2,150–2,250° F, the molybdenum high speed steels from 2,150–2,250° F, and the cobalt high speed steels from 2,325–2,400° F. For forging, the steel should be heated slowly and uniformly to 2,050–2,150° F. It is not safe to continue forging below 1,700° F. Slow cooling after forging is necessary to prevent possible cracking from forging strains (see *Metals Handbook,* 1948 Ed., pp. 286 and 663).

Furnaces: For hardening high speed steel, atmospheric-control furnaces satisfy a demand for more accurate dimensional control and a surface not injured during heating. Both electrical and gas-fired types of furnaces, where the atmosphere is independent of the source of heat, are available. This permits control of the atmosphere in contact with the work. The ideal atmosphere would be neutral to the steel.

Salt baths: With tools that cannot be ground after hardening, or when it is necessary to keep the surface in the best possible condition and preserve sharp edges, salt-bath heating for tempering, annealing, carburizing, and hardening will give the best results. Fresh salt has a dissolving action on the steel, which disappears after the bath is used for a short time. A sludge gradually forms at the bottom of the pot and a heavy crust on the top. These must be removed periodically. The use of salt baths, various types of which furnish temperatures up to 2,400° F, and types of salt are described in detail in *Metals Handbook,* 1948, p. 283. From the salt bath, tools are quenched in hot water to dissolve the salts. **Lead baths** furnish temperatures up to 1,700° F (*Metals Handbook,* p. 291). As the vapor is poisonous, lead furnaces should be equipped with ventilating hoods. Lead baths do not affect quenching oils used subsequently.

To cut hardened high speed steel bars a thin abrasive wheel of 40–60 aluminum oxide grit, bonded with shellac or resinoid, should be used. Or the point of fracture should be nicked on all four sides and should be heated to a dull cherry red (1,400–1,500° F) before breaking.

SURFACE TREATMENTS FOR HIGH SPEED STEEL TOOLS

Several surface treatments for high speed steel tools which can be recommended for certain applications include nitriding, chromium plating, oxidation, superfinishing or honing, liquid honing, and peening.

These treatments improve tool life by (1) increasing surface hardness, (2) increasing wear resistance, (3) preventing seizure between tool and chip, (4) lowering the coefficient of friction and lessening the heat generated, or (5) distributing the load more uniformly over the cutting edge. Many of these factors are interrelated; for example, an increase in hardness reduces wear resistance; tool wear is lessened by the prevention of seizure; and seizure becomes less as friction is reduced.

Nitriding by the liquid-salt process is perhaps the most successful and widely used. Tools so treated possess exceptional hardness and wear resistance, a relatively low coefficient of friction, and a satisfactory resistance to softening at elevated temperatures. The hardened, tempered, and ground tool should preferably be preheated in a neutral salt bath or an air convection furnace to a temperature of 1,000–1,050° F and then transferred to the nitriding bath of a 60–40 per cent mixture of sodium cyanide and potassium cyanide at approximately 1,040–1,050° F, where it is held for 20–30 min. The tools are air cooled, washed in warm water, and dried. They are then ready for use. A freshly prepared bath must be aged for about 12 hr at 1,000–1,100° F to promote the formation of cyanate, the active agent of the bath, before being used.

The thickness of the nitrided case is from 0.0005 in. to 0.003 in. and is very hard (see Table VII-7), but the tool must be renitrided after the surface is ground.

Nitriding has shown least effect on twist drills and single-point tools and the most benefit on chasers, taps, reamers, form tools and broaches, and on some milling cutters and counterbores.

Chromium plating of high speed steel is applied to increase hardness and reduce friction on such tools as drills, taps, reamers, forming tools, files, broaches, cutoff saws, milling cutters, and drawing dies, where failure occurs by wear.

An electrolytic bath made up of chromic acid and sulphuric acid is operated at a temperature between 110 and 150° F with a current density between 120 and 200 amp per sq ft. Thicknesses of plate between 0.0001 in. and 0.00015 in. have the highest hardness of 900 Vickers and the brightest luster. See Table VII-7.

Plating is also accomplished by the Electrolizing process, by which the chromium is electrically vaporized and deposited on the tool in a vacuum.

Oxidation of high speed steel tools is used to increase tool life by effecting a decrease in the coefficient of friction between the tool and the work. Indications are that it is not as effective in promoting tool life as chromium plating or nitriding. Oxidation may be achieved by heating to about 1,050° F in a steam atmosphere or by treating in liquid salts such as sodium hydroxide and sodium nitrite at about 285° F from 5 to 20 min. The black oxide coating formed will not chip, peel, or crack, and has a thickness generally less than 0.0002 in.

Superfinishing has been widely publicized as a means of approximating the perfection of finish on the surfaces and edge of cutting tools that is desirable for long tool life. It has been shown that for light cuts longer tool life may be obtained by the keener cutting edge and smoother flank and face. The average carefully ground tool has surface roughness of about 25–40 microinches r.m.s., while tools carefully honed have roughness values from 1 to 6.

Peening with small steel shot is a method for plastically deforming and cold working the surface of a material to introduce residual compressive stresses. This operation on cutting tools has been reported to increase tool life materially.

Liquid honing combines to some extent the characteristics of superfinishing and shot peening and has been used to improve tool performance. Primarily this is a honing process based on the use of a fine abrasive mixed with an emulsion and discharged by compressed air against the metal surface to be polished or finished. Because of the fineness of the abrasive used, the cold working is not as high as that caused by shot peening. Its success on cutting tools, if any, is due largely to the reduction of surface and cutting-edge roughness.

Cast Nonferrous Metals

Stellite, first introduced in 1915 and now used in the form of star-J-metal, 98M2 and 2400, is a nonferrous metal. It consists chiefly of 43–48 per cent cobalt, 17–19 per cent tungsten, 30–35 per cent chromium, and 1.85–2.15 per cent carbon. This material, like **Crobalt and Deloro Nos. 40 and 80,** is cast to any desired shape and is finished by grinding. It is brittle and cannot be forged. The outer surface is hardest and, therefore, should form the cutting edge and face of the tool. Except for slight changes in color, Stellite is not affected by heat up to 1,500° F. It is tougher at dull red heat than when cold, and is an excellent material for resisting abrasive action. Stellite cuts best at speeds 50–100 per cent higher than those for high speed steel. Recommended shapes for tools of this metal are shown in Figs. VII-14 and VII-15. It costs about $8 per lb.

Sintered Carbides

Sintered-carbide tools were introduced commercially in this country in 1928. Three types of **carbides** are now used: tungsten carbide (WC), tantalum carbide (TaC), and titanium carbide (TiC). The carbide or combined carbides are mixed with a **binder** of cobalt or nickel, and either pressed under heavy hydraulic pressure into slabs or ingots from which special shapes are subsequently cut, or pressed directly into blanks of the desired shape and size. The blanks are then semisintered in a nonoxidizing atmosphere at temperatures below 1,472° F. In this state, the material can be further formed, if desired, by machining. Next step is the final sintering at 2,462–2,822° F, and the resulting product, **sintered carbide,** is so hard that its shape can be changed only by grinding. Standard shapes of tips are shown in Fig. 18.

The desired hardness and strength for specific applications are obtained generally by varying the proportion of the **carbide and binder.** Basically, all sintered carbides are made from the carbide of tungsten. Carbides of tantalum and/or titanium supplement the tungsten carbide to form combined carbides known as tantalum or titanium carbide.

Sintered-carbide tools usually are made by brazing small shapes to form the tool tips to the end of shanks of SAE 9155, SAE 2340, or SAE 1045 steels. This is necessary, as the sintered carbides have about half the transverse rupture strength of high speed steels, and consequently the tips must be well supported in heavy, less expensive shanks, Fig. 19.

A standard ⅜-in.-sq straight-shank turning tool, tipped with sintered carbide completely ground, is priced as low as 85 cents. A solid bit of W–Cr–Co cast alloy is priced at 90 cents, while a high speed steel bit costs about 25 cents. Both the latter tools must be ground to shape, whereas the carbide tool is furnished ground ready for use.

The tips of high speed steel, cast alloy, and carbide may be **clamped or brazed** to the shanks, using copper which melts at 1,983° F, Tobin bronze which melts at 1,625° F, or silver solder which melts at 1,300° F. The tips of high speed steel should be tempered after all but silver brazing. There should be liberal fluxing of the joined surfaces with borax. The brazing can be carried out in the furnace with or without hydrogen as a furnace atmosphere, or by using a nonoxidizing flame of an oxyacetylene torch. The tool shank should be sand blasted or well cleaned with carbon tetrachloride and well fluxed. It may be recessed on one or two sides to receive the tip, or the tip may be brazed on the top of the tool shank.

For **furnace brazing,** the shank coated with borax is preheated to 1,500° F and withdrawn. The tip is then inserted in the recess with a small piece of sheet copper or Easy-Flo No. 3 between the tip and shank. The tool is then placed in the high-heat muffle and raised to 2,050° F, at which temperature the copper melts to form the joint between the tip and shank. Induction heating is also used to heat the assembly of the tip, brazing medium, flux, and tool shank. At this point, the assembly is withdrawn and the tip is pressed into place with a steel rod to squeeze out excess copper and flux. For larger or irregularly shaped carbide tips, the sandwich braze reduces strains between tip and shank. This consists of layers of flux 0.005

in. thick, Easy-Flo No. 3 sheet, flux 0.005 in. thick, Constantan sheet, flux, Easy-Flo, and flux placed in order between tip and shank before heating. Brazing temperature for Tobin bronze is 1,750° F and for silver solder, 1,475° F (*American Machinist*, March 8, 1939, p. 130). " Cinch " has a working temperature lower than that for drawing high speed steel.

Diamonds and Sapphires

Diamonds, known to the trade as " carbon " or " bort," are the hardest material known. They may be lapped to smooth surfaces and keen edges, and because of their low coefficient of friction on metals make excellent finishing tools. Industrial diamonds cost from $5 in the rough to $20–$30 shaped, per carat. Tools of **sapphire** made synthetically withstand temperatures up to 3,000° F, can be polished to high finish, are nonmagnetic, and have a very low coefficient of friction.

Ceramic Tools

Experimental tools of ceramics are brittle but have shown excellent heat and wear resistance and have given tool-life values between those for tools of cast nonferrous metal and sintered carbides.

GRINDING SINGLE-POINT TOOLS

Cutting tools should be kept sharp by being ground often, rather than allowed to become broken down before being replaced. Better cutting results, such as accuracy and finish with less power and with less wear and tear on the machine tools, will be obtained if the tools are kept sharp and never allowed to become extremely dull. Instead of allowing each machinist to leave his machine idle while grinding tools according to his own judgment, it is better to have trained men properly equipped to take care of all tool grinding at some central point near the tool crib. Waste can be avoided by standardizing the materials and shapes of tools used for various purposes, so that they can be ground in quantities.

In grinding tools, light pressures should be used and the cutting edges should not be heated excessively. A tool should be ground either completely dry or with a copious supply of coolant of water, borax water, or emulsion. Tools should not be ground dry and periodically dipped into water to be cooled, as such temperature changes produce minute cracks along the cutting edge, which lead to early failure of the tool. Keen cutting edges and smooth surfaces should be provided.

Grinding wheels: Soft, free-cutting wheels should be used for grinding cutting edges. Specific wheels for each tool material are used as follows: **carbon tool steel,** high speed steel, cobalt high speed steel, and cast nonferrous tools are best rough ground on a coarse-grain (A36L vitrified bond) wheel, and finished on a fine-grain (60) wheel operating at 5,000–6,000 fpm. The coarser grains may be used on machine grinders and a lower speed of 4,000 fpm on cast metal.

In grinding **sintered-carbide tools,** two types of wheels are used: (1) Special green silicon carbide abrasive, which is hard and sharp. It is bonded into an open, porous, and soft structure. (2) Diamond wheels in grits from 100 to 320 grain size. For roughing, on offhand or semiautomatic machines, a straight or cupped wheel of silicon carbide abrasive, 60–80 grain, vitrified bond, and soft grade is used, such as C60I7V, or a resinoid wheel with 100-grain diamond as D100L100B. For finishing, on offhand or semiautomatic machines, a similar vitrified wheel of 100–150 grit is used, or a diamond-resinoid wheel of 150–220 grit. For offhand grinding, the wheel should be slightly crowned and the tool rocked slowly across the face of the wheel, which rotates at 5,000 fpm. Metal and vitrified bonds are also used for diamond wheels.

Tools finished on silicon carbide wheels may be lapped on the flank and face for close-limit, precision work on a Belgian iron or vanadium-cast-iron lapping disk impregnated with No. 4 diamond powder (600 grit) or boron carbide, moistened slightly with olive oil, and rotating at 500–1,000 fpm. Grinding and lapping should be done in a direction against the cutting edge. Lapping should continue until all grinding marks are removed.

Effective **chip control** is essential in machining steels at high speeds as used with sintered-carbide tools. Normally, long continuous chips of large radii are produced which are difficult to handle and are hazardous to the safety of the machine operator. A chip which curls into a tight helix or spiral and breaks up into short sections against the unfinished surface of the work, the tool, or tool post is preferred. Chips from metals such as brass and cast iron, which are normally broken up, require no special tool treatment for chip control.

The chips may be controlled by:

1. Obtaining a proper ratio between feed and depth and side-cutting edge of the tool.
2. By the correct combination of back- and side-rake angles.
3. By mounting a block either on the tool itself or on the toolholder against which the chip impinges and breaks itself.
4. By grinding a chip breaker in the face of the tool.

Several types of chip breakers are provided, such as the V groove in the tangential bar-turning bit, Fig. 30, the shelf ground parallel or at an angle to the cutting edge below the normal face of the tool about 0.020 in., or equal to the feed, and having a width from the cutting edge to the shoulder equal approximately to the depth of cut as shown for the angular type *B* in Fig. 26. The parallel type *A* is used for cutting when the depth of cut varies, and the angular when the depth is relatively constant. For normal turning the chip-breaker angle is 8–10 deg from the side-cutting edge, but for very shallow cuts the chip-breaker angle might be 30–45 deg from the side-cutting edge. Another ground-in chip breaker, type *C*, is obtained by grinding a groove in the face of the tool back of the cutting edge so as to leave a ridge on the face of the tool of 1–1½ times the feed in width. The groove depth should be not more than 0.010 in., and the width from 3 to 4 times the feed. Type *D* chip breaker may have the

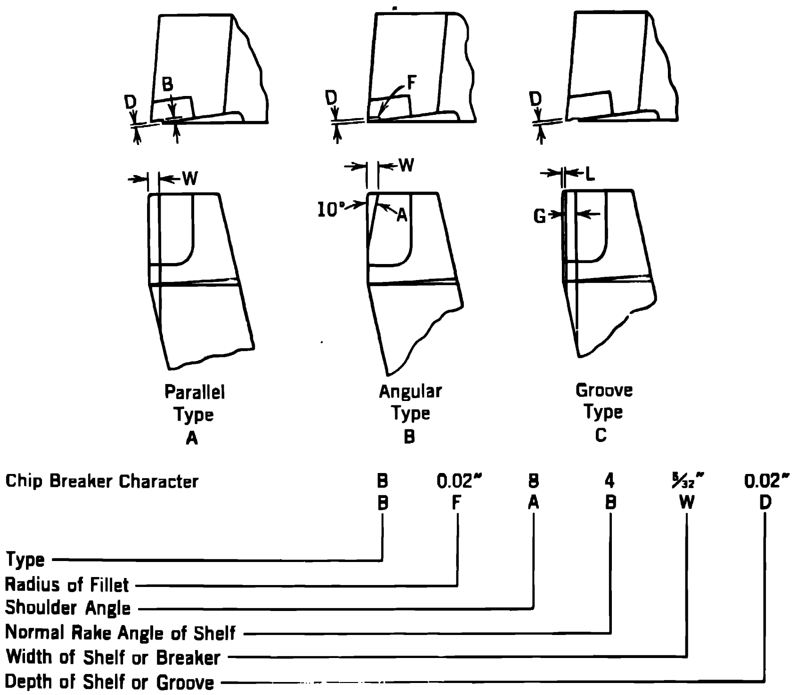
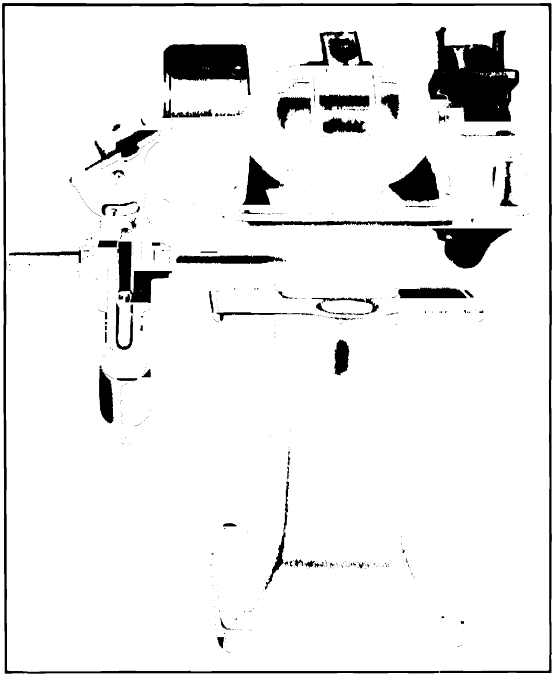


FIG. 26. Chip Breakers, Types *A*, *B*, and *C*.

Ground-in angular chip breaker, type B, for sintered-carbide-tipped tool, style BR. Dimensions of breaker are for a variable depth of cut of ⅛ in. in steel with a feed of 0.02 in.

ground-in groove with the ridge ground to a 0 or slight negative rake, and type *E* may have a deeper groove with a large fillet between the face and shoulder so that the ridge having a 0 or negative rake is somewhat below the normal tool face.



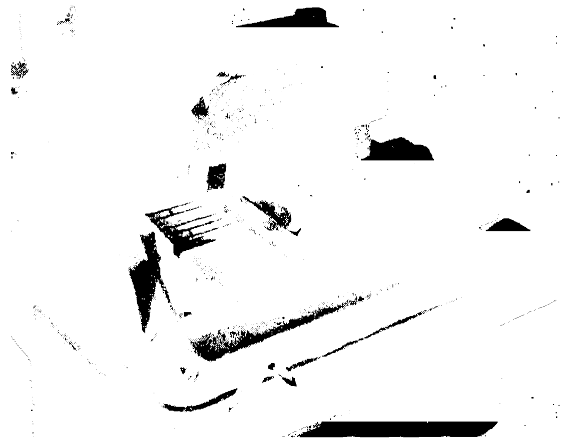
Courtesy United States Electrical Tools.

FIG. 27. A Model 72 High-Speed, Tool-Bit Grinder, Showing a Cup Wheel with a Tilting Table on the Left and a Straight Wheel with a Flat Work Support on the Right.

The straight wheel, $12 \times 2 \times 1\frac{1}{8}$ in., of A46J5V6, is used for roughing tool bits, and a cup wheel, $12 \times 4 \times 1\frac{1}{2} \times 1\frac{1}{8}$ in., of A60J5V6, for finishing.

The most satisfactory means of grinding a chip breaker in the face of a carbide tool is to use a tool and cutter grinder or a surface grinder equipped with a universal vise and a straight resinoid-bond diamond wheel of 100 or finer grit. The side of the wheel to grind the shoulder should be provided with a radius of 0.010–0.030 in. The tool should be set so that the wheel will cover the full width of the chip-breaker shelf and feed along the cutting edge parallel to it or at an angle, as desired, with an in-feed of not more than 0.0005 in. per pass until the proper depth is reached. See Fig. 36.

Single-point tools may be ground offhand, that is, with no support under the tool. They are more often machine ground while resting on a fixed support, on a table with a guide, protractor, or vise, so that the tool may be adjusted in relation to the wheel, and any angle may be ground and duplicated. Machine grinding is much preferred, as better surface quality and more accurate angles can be obtained.



Courtesy Ex-Cell-O Corp.

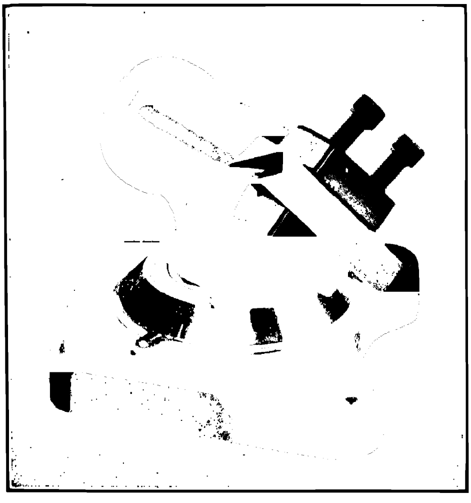
FIG. 28. The Ex-Cell-O No. 49 Single-Point Tool Grinder.

This has two cup wheels, 14 in. O.D. by 4 in. bore by 11 in. recess diam., with steel back bored to 1.250 bore. A 2-hp, 1,800-rpm motor in the base drives the spindle at 1,350 rpm to give 5,000 fpm grinding speed. A carbide-tipped tool is shown positioned on the table by means of a protractor for grinding the end-cutting-edge angle. The table is tilted by the crank to the desired relief angle.

Offhand grinding on an ordinary two-wheel bench or floor grinding stand is common practice. Such a grinder with a straight wheel and a flat work rest is shown on the right side of the machine in Fig. 27, in which the operator holds the tool in the grinding position by hand. The results obtained cannot be relied upon to insure high cutting efficiency or to duplicate shapes of tools. This type of grinding is not recommended except in small shops by trained mechanics. A stand grinder with a tilting table and adjustable guide for the tool is shown for the cup wheel at the left side in Fig. 27 and in Fig. 28. The end relief is being ground as the tool bit is moved across the face of the wheel. Such grinders are very convenient for both small- and large-quantity tool grinding. The table and protractor are first adjusted to grind the tool face and then readjusted to grind the end and side flanks. The nose is formed by hand grinding, as illustrated

Fig. 29. Sellers Number 20W Single-Point Tool Grinder for Steel or Sintered Carbides.

The tool reciprocates past the wheel face in the tangential plane so as to grind flat surfaces with only a line contact with the wheel. The toolholder is universal so the tool can be clamped in any position for grinding the face or flank. A rear view of the machine is shown at the left; a front view of the toolholder and wheel is shown at the right. The face of a tipped tool is being ground. For high speed steel tools the wheel is 15 in. diam. and 1⅜ in. face of 38A80-J6V, and for sintered-carbide tools it is 15 in. diam. and ¾ in. face of C80-I5V.



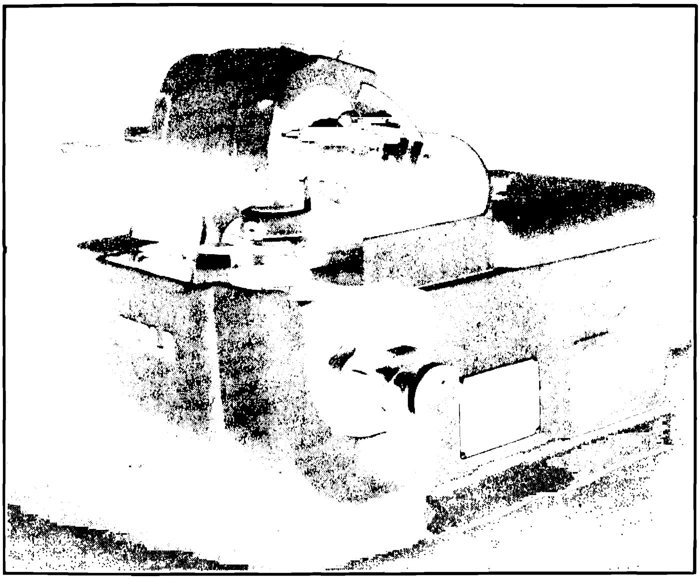
Courtesy Boyar Schultz Corp.

Fig. 30. The Model G Universal Grinding Fixture for Surface Grinder Magnetic Chuck Use.

A bar turning tool is shown clamped in position for grinding a chip control groove; a ridge approximately 0.015 in. wide remains along the cutting edge and nose.

in Fig. 35. Usually a roughing wheel is on one end of a stand grinder and a finishing wheel on the other.

A semiautomatic tool grinder for large or small single-point tools is represented by the Sellers model 20 in Fig. 29. The tool is held in a universal vise which is adjustable to any desired position, as the face, end, and side flanks are ground. The tool is rocked vertically past the face of the straight wheel while fed slowly toward it.

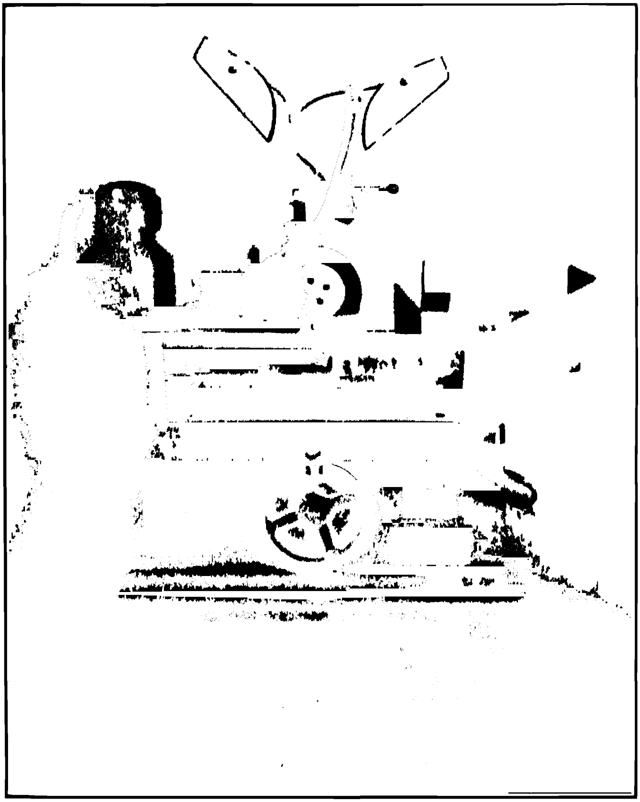


Courtesy Heald Machine Tool Co.

FIG. 31. The Heald Model 2 Tool Sharpener.

The left end of the spindle carries a coarse wheel, table, and protractor for rough grinding small single-point tools preliminary to generating the finished end with the tool clamped in the universal head with the cup wheel on the right end of the machine spindle. The head is adjusted for desired relief angle, and the swivel stops set for end-cutting- and side-cutting-edge angles and for nose radius. Once set, the machine goes through an automatic grinding cycle.

Tool and cutter grinders such as those used in grinding milling cutters, reamers, etc., are also used in grinding single-point tools, as the universal vise, Fig. 30, permits the adjustment of the tool to any compound angle required. It is good practice to grind the face of the tool on such a grinder or on a surface grinder equipped with a universal vise to hold the tool or bit to the correct back- and side-rake angles. The end and side flanks may then be ground after adjusting the vise, or the end and side flanks may be ground more rapidly on a two-wheel grinder with a table support provided with a protractor, which is reciprocated with the tool parallel to the face of the wheel. The protractor is supported and slides in a slot in the table, as shown in Fig. 28.

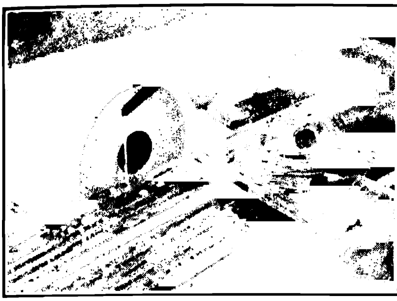


Courtesy Norton Co.

FIG. 32. The Bura-way Single-Point Tool Grinder.

Two master blocks under the front edge of the table tilt it to the proper table relief angle, and a small master block in the toolholder provides a relief angle to the toolholder. The setting block for adjusting the overhang of the tool in the holder in relation to the template for grinding the end-cutting edge, the nose, and the side-cutting edge for the single-point tool, is shown at the right of the grinding wheel.

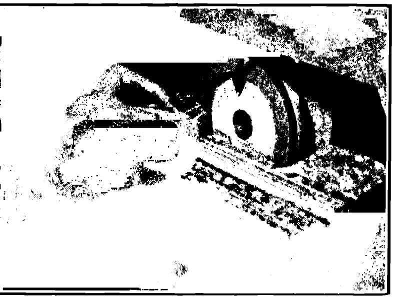
This machine has two tilting tables, so that the tool may be roughed on one side and finish ground on the other, or one wheel may be for finishing high speed steel and the other for sintered-carbide tools. Wheels for high speed steel are recommended as A46-JV for rough grinding (60-JV), A60-JV for semifinish grinding (C80-JV), and A80-JV for finish grinding (C100-JV), the values given first for high speed steel, and those in parentheses for sintered carbide.



Courtesy Norton Co.

FIG. 33. Finish Grinding the Side-Cutting Edge of a Left-Cut, Left-Offset, Carbide-Tipped Tool, Using a Protractor Tool Guide and a 220-Grit Vitrified Bonded Diamond Wheel Marked D220-P100V1/16.

For roughing and finishing with a single wheel, a 150-grit diamond would be used. The small stream of emulsion keeps the wheel face clean as the tool is moved slowly back and forth across the face of the wheel.

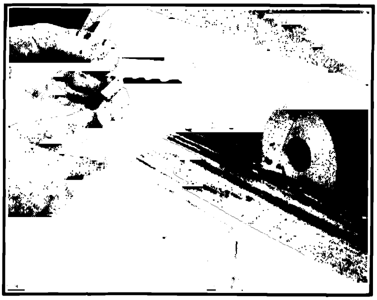


Courtesy Norton Co.

FIG. 34. Finish Grinding the End-Cutting Edge and Front Relief with a 220-Grit Vitrified Bonded Diamond Wheel.

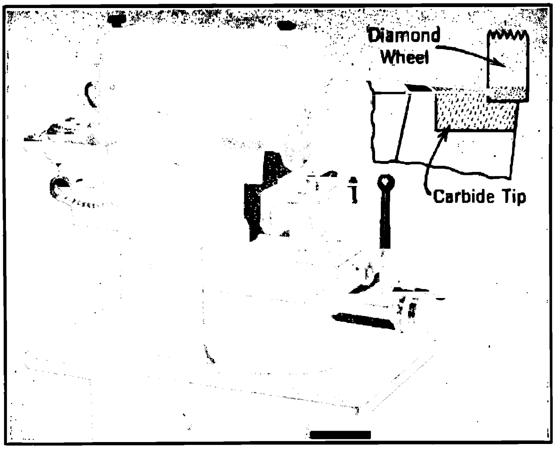
The protractor for holding the tool in position against the wheel is under the operator's left hand.

The **surface grinder** provided with a universal vise or special fixtures is also used for grinding the face and flanks of tools. A special universal vise for surface-grinder work is illustrated in Fig. 30. A semiautomatic grinding machine preparing small bits or boring tools is illustrated in Fig. 31. The Norton **Bura-way grinder,** Fig. 32, has a single cup wheel and a table which may be tilted to any angle from the horizontal by means of blocks. The tool is held in a toolholder, the upper part of which holds the tool and also is tilted by means of an inserted block. With the tool and holder at right angles to the end of the wheel, a relief angle equal to that of the table plus that of the toolholder is ground. As the tool is swung to the side, the angle of the toolholder is minimized and a smaller relief angle is provided for the side-cutting edge. The toolholder carries an enlarged tem-



Courtesy Norton Co.

FIG. 35. The Nose Radius on a Carbide-Tipped Tool Is Being Checked against a Radius Gage after Being Ground on the Face of a Cupped Diamond Wheel.

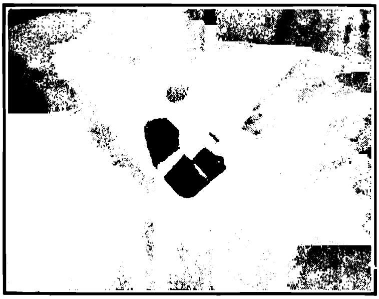


Courtesy Hammond Machinery Builders, Inc.

FIG. 36. The Model CB-77 Chip Breaker and Diamond Finishing Grinder.

The cup diamond wheel is mounted on the left, and the straight wheel for grinding chip breakers is on the right. The tool in the vise is traversed in the plane of the wheel while the work is being raised to depth. The chip-breaker wheel, 4-6 in. diam., ⅛-½ in. face of 1¼ in. hole, is designated as D320-N100V1/16.

plate of the tool profile, which bears against a straight edge under the grinding wheel, so that tools of the same shape can be ground in large quantities.



Courtesy Norton Co.

FIG. 37. Dubbing Off the Keen Cutting Edge of a Carbide-Tipped Tool at a 45-deg Angle to the Top Face for a Width of about 0.004 in. Prevents Chipping of the Cutting Edge on Heavy Cuts in Steel.

A ¼ in. × 7/16 in. × 4 in. 320-grit diamond vitrified bonded hand hone, marked D320-V1 16, is used. A silicon carbide abrasive stick marked 37C280-NV may also be used for this purpose.

The **Hager carbide tool grinder** has two double-faced wheels and is equipped with a universal vise to hold the tool, which can be presented to the left face of the left-hand wheel for rough grinding, then transferred on a notched bar to the same relative position of the right-hand wheel for finish grinding. Also, the tool may then be adjusted and rough ground on the right face of the left-hand wheel and then transferred to the corresponding position of the right-hand wheel for finish grinding.

A two-wheel grinder with tilting table with diamond facing wheels for sintered-carbide tools is illustrated in Figs. 33–35 to show the successive operations in grinding the side, end, and nose radius of a tipped tool. The chip breaker is being ground in Fig. 36.

Figure 37 shows the method of honing the face and flank and dubbing off the keen cutting edge of a sintered-carbide tool for improving its performance in turning steel.

QUESTIONS

1. Define a single-point tool and name its principal parts.
2. What are the principal angles of a single-point tool, which influence its tool life and the cutting forces? Describe the character representing the shape of a single-point tool.
3. What is meant by a tipped tool? Name the materials which are used as tips.
4. Name eight tool materials used for single-point tools and state the characteristics of each in regard to hardness, hot hardness, and permissible cutting speeds.
5. What are some of the surface treatments given high speed steel tools and what is the advantage of each?
6. What types of grinding wheels are used for sharpening high speed steel tools?
7. What two types of grinding abrasives are made up into wheels for grinding sintered-carbide tools?
8. What is meant by a chip breaker and when should it be used, considering the tool material and material cut?
9. Name and describe several types of grinders for single-point tools.
10. Explain the difference between true rake, side rake, and normal rake.
11. Explain the difference between side relief, normal side relief, and normal side clearance.

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CHAPTER VI

CUTTING FLUIDS

Definition

Cutting fluids, frequently referred to as lubricants or coolants, comprise those liquids and gases which are applied to the work and tool to assist in the cutting operation.

In metal cutting, it is desirable to have high cutting speed, long tool life, low cutting temperature, low power consumption, the best surface finish, good chip removal from the tool, with work and machine free from corrosion. In different operations these factors vary in importance and usually some are obtained at the expense of others. For instance, in heavy roughing cuts, temperatures which affect distortion and surface finish are of little consequence, and maximum removal of metal per tool grind is of most importance. In screw-machine work, however, surface finish, dimensional accuracy which affects interchangeability, and long tool life are of great importance.

Purposes

The **purposes** for which cutting fluids are used may be summarized as follows. Each may be realized with varying degrees of success.

1. To cool the tool, preventing its being heated to high temperatures, thereby reducing its hardness and resistance to abrasion. Tools wear faster at higher temperatures.
2. To cool the work, preventing its being machined in a warped shape resulting in inaccurate final dimensions.
3. To lubricate: (*a*) thereby the energy or power consumption in removing metal is reduced; (*b*) abrasion or wear on the cutting tool is reduced, thereby increasing the life of the tool; (*c*) by virtue of lubrication, less heat is generated and the tool therefore operates at lower temperatures with the tendency to extend tool life; and (*d*) chips are helped out of the flutes of drills, taps, saws, broaches, etc.
4. To provide a good finish of the work.
5. To cause chips to break up into small parts rather than remain as long ribbons which are hot and sharp and frequently difficult to remove from the machine.
6. To wash the chips away from the tool. This is particularly desirable in deep-hole drilling, hack sawing, and milling.

The **properties** desired in any kind of cutting fluid may be summarized as follows:

1. **High heat absorption.** The time rate of heat absorption or thermal conductivity presumably is of greater importance than high specific heat.

2. **Good lubricating qualities** as outlined under (3) of *Purposes* above.

3. **High flash point,** not liable to spontaneous combustion, so as to eliminate the hazard of fire.

4. **Stability,** so as not to oxidize in the air or give rise to gummy deposits on the sliding surfaces of the machine. Solids should not separate out at ordinary working temperatures.

5. The components should remain **neutral.**

6. Remain **odorless** even when heated or after continued use.

7. Should be **harmless** to skin of operator, avoiding high acidity, excessive drying, or carrying bacteria.

8. **Harmless to the bearings** of the machine even if mixed with the machine lubricants or applied directly to the bearings.

9. **Noncorrosive** to the work or the machine.

10. Fair **transparency** for many operations so that the cutting action of the tool may be observed.

11. **Low viscosity** to permit free flow from work back to storage tank and to drip from chips.

12. **Low priced** and readily obtainable.

Classification

Cutting fluids may be classed as follows:

1. **Dry** or air used as suction or blast (D).

2. **Water,** either plain or containing an alkali, salt, or water-soluble additive, but little or no oil or soap (WS).

3. An **emulsion** (W Em), which is a mixture of water and a soluble oil (W Sol O) or paste (W Sol P) in which water carries combinations of oil, fats, wax, or chemicals in colloidal or finely dispersed suspension.

4. **Straight oils:** (*a*) straight mineral (petroleum) oils (MO), kerosene (K), low-viscosity petroleum fractions, such as mineral seal (MS), or higher-viscosity mineral oils (MO); (*b*) straight fixed or fatty oils (FO) consisting of animal, fish, vegetable, or synthetic equivalents; lard oil (LO).

5. **Mixed oils,** a combination of straight mineral and straight fatty oils, such as mineral-lard (MO LO) and mineral-fatty oils (MO FO).

6. Straight oils or mixed oils may be **sulphurized** or **chlorinated** or contain other elements or substances, such as graphite, mica, talc, or phosphorous compounds.

For example, a **sulphurized mineral oil** (S MO) is a mineral oil containing effective sulphur compounds; a **chlorinated mineral oil** (Cl MO) is a mineral oil containing effective chlorine compounds; a sulphurized-chlorinated mineral oil (S Cl MO) is a mineral oil containing effective sulphur and chlorine compounds.

Cutting oil bases (BO) are concentrates usually designed to be blended with mineral oils to meet specific requirements. A sulphurized base oil blended with 10 parts of light mineral oil to give a final oil of 140 SSU at 100° F would have a character of S BO MO (1–10) (140 vis.).

Water emulsifiable " soluble " oils (W Sol O) or pastes (W Sol P) are prepared fluids or pastes designed to be mixed with water to form emulsions (W Em) to meet the requirements of each job.

The Application of Cutting Fluids

Air as induced draft is often used with internal and surface grinding and polishing operations or on grinding and boring operations on gray iron. Its main purpose is to remove the small chips or dust from the air, although some cooling is obtained.

Aqueous solutions, containing about 1 per cent by weight of an alkali, such as borax, sodium carbonate, or trisodium phosphate, have high cooling properties and have sufficient corrosion-prevention properties for some jobs. They are inexpensive and are sometimes used for grinding, drilling, sawing, light milling, or turning operations.

Emulsions form the greatest volume of cutting fluids used today. A soluble oil or paste consists generally of mineral oils held in suspension by an emulsifying agent such as sulphonated oils or soaps. A " coupling agent " or mutual solvent such as alcohol or glycol is combined in the soluble oil. When mixed with water, the soluble oil or paste produces an emulsion which usually looks like milk, although some are clear. The use of hard water is inadvisable, but with a softener it may serve adequately in some cases. The small particles of oil are held in suspension in the water in such a manner that separation due to differences in specific gravity or density is very slow. These solutions, consisting of 1 part of the oil to 10–100 parts of water, depending upon the oiliness required, have a low viscosity and high specific heat, are oily and noncorrosive, and give very good results at low cost for practically all types of metal cutting and grinding when machining all types of steel, aluminum alloys, malleable cast iron, etc.

For most operations, a solution of 1 part soluble oil to 20 parts water will be satisfactory for turret-lathe work, some screw-machine work, gear hobbing, milling, and drilling. The mix of the emulsion is often determined by the rust-prevention requirements of the metal being machined, or the lubrication requirements of the machine, and not by the actual machining operation.

A wide variety of **oils** is used in the metal-cutting industry. The oils are used where lubrication rather than cooling is essential or where a high-grade finish is desirable. In general, the specific heat of oils varies between 0.4 and 0.6 as compared with unity for water.

The **mineral oils** are available in viscosities ranging from 35 (seconds Saybolt Universal) (at 100° F) for kerosene, 45 for mineral seal, and 75–250 for the heavier oils. As straight oils they have a limited usefulness in metal cutting, probably because of their low degree of adhesion or lack of oiliness. They are very stable and do not have many disagreeable features characteristic of fixed oils. Their specific heat and price are relatively low. The low-viscosity oils (MO, 100 vis.) are used for high-speed screw-machine work for turning and shaping steel, copper, brass, and aluminum alloys. The heavier oils, usually containing a small amount of fixed oil or sulphur, are used for broaching and tapping. The lower-viscosity oils are usually more transparent, flow more freely, allow small chip particles to settle out quicker, and give a greater recovery from the chips. See Table 1 for properties of some mineral oils. The autogenous or self-igniting temperature of kerosene is about 482° F, the fire point is 155° F, and the Cleveland open-cup flash is 150° F.

The **fixed oils** differ from the mineral oils in that they are saponifiable, i.e., soap can be made from them with the aid of soda or potash. They have higher flash points, greater adhesiveness or oiliness, relatively higher specific heat, and a slower change of fluidity with a given temperature change. On the other hand, they are much more expensive, become rancid, liberate free fatty acids, develop disagreeable odors, and become gummy or dry when used as straight oils subjected to the high heat developed in the cutting area.

TABLE 1. PROPERTIES OF SOME TYPICAL MINERAL OILS*

Material	Producer	Brand Grade	API	Viscosity at 100° F	Cleveland Open-Cup Flash, ° F	Fire, ° F	Pour	Color NPA
Mineral Seal	Sinclair Ref. Co.	Mineral Seal 300	38.5	40–44	265	300	30	1
100 at 100	Gulf Ref. Co.	Neutral	29.0	103	360	420	25	1
100 at 100	Shell HVI	Neutral 100	32.0	120	370	425	5	1½
160 at 100	Sun Oil Co.	Solvent Refined #160	30.5	150–160	400	460	0	1–1½
160 at 100	Texaco	150 Pale	20.0	150	310	360	5	Pale

* Courtesy W. H. Oldacre, D. A. Stuart Oil Co.

Of the **animal oils** there are lard, tallow, neatsfoot, wool, horse, sperm, whale oils, etc. Lard oil has been used for years as the best cutting oil for difficult work, such as threading and tapping, because of its oiliness or high degree of adhesion to the metal. It is now used principally for compounding or as a base for soluble oils and sulphurized oils.

Fish oils are not used extensively in metal-cutting operations because of their odor. **Vegetable oils** having slow-drying properties, as required of cutting oils, are used principally in compounding. These oils consist of olive, corn, rapeseed, cottonseed, castor, and soybean oils, and the distillate oils (not fixed), such as turpentine and resin.

Most of the oils used for metal cutting are **mixed.** In this way, the good properties of the mineral and fatty oils are combined. Mineral-lard oil is a term often used to designate such a mixed oil. From 5 to 50 per cent lard oil is added to the mineral oil (MO LO, 19–1). Sometimes 1–5 per cent free fatty acid, such as oleic, is also added Mixtures are used successfully for turning, drilling, reaming, milling, tapping, and threading steel, wrought iron, brass, bronze, and aluminum. They also are used extensively on screw machines and gear-cutting machines for finishing work. Lard oil and turpentine in varying proportions are used for machining aluminum, very hard steel, and drilling glass. Lard oil and kerosene are used for milling aluminum and copper.

Sulphurized oils are now used as all-round cutting fluids for rapid production involving good surface finishes and close tolerances on metals difficult to machine. By sulphurized oils is meant those oils which contain sulphur in a chemically active state. Flowers of sulphur may be stirred into light mineral oil for use in wire-drawing, press-working, or metal-cutting operations. The sulphur, however, is apt to settle out of the oil and its benefit be lost unless it is constantly agitated. Cutting-oil manufacturers are now producing, by various processes, mineral oils having chemically active sulphur up to 3 per cent in permanent combination. These oils are purchased ready for use. The sulphur aids materially in preventing seizure between two metals, and for this reason is used for extreme pressure lubrication.

A sulphurized base oil is also available which consists of a fatty oil carrying 6–12 per cent active sulphur in chemical combination. These base oils are usually of high viscosity and very dark in color. They are diluted by the user with 5–20 parts of low-viscosity inexpensive mineral oil such as 28 gravity paraffin or red engine oil to meet the requirements of each job. With 6–12 parts of a light neutral oil, a clear amber-colored liquid is obtained very suitable for automatic screw-machine work.

Large quantities of these sulphurized oils are used with great success on automatic screw machines and various sorts of high-speed operations. They are particularly advantageous on those operations involving tough, stringy, and unusually soft metals, such as Monel, nickel, stainless steels, wrought iron, and other metals difficult to machine. Operations on which they excel include threading, broaching, reaming, gun drilling, and screw-machine work. The sulphur will stain some metals, such as brass, copper and aluminum, and for that reason may be objectionable.

Some sulphurized oils, which also contain chlorine, have been found to give satisfaction in all types of metal-cutting operations. Some mineral and base oils containing only chlorine also have shown excellent machining properties. There is danger, however, of the liberation of free chlorine, which may prove objectionable. Certain materials, such as carbon tetrachloride, are very beneficial in machining hard and tough steels or soft metals, but should be used only with the greatest care, as with chloroform and other highly volatile solvents harmful physiological effects may follow.

Some metals require specific types and applications of cutting fluids which may be summarized as follows:

1. In machining **aluminum** the cutting may be done dry, but for better tool life and surface finish, light mineral oils are used. Kerosene has peculiar properties which serve this purpose. Low-viscosity oils, such as mineral seal or mineral seal blended with kerosene, also give good results. Kerosene, up to 15 per cent, is frequently added to emulsions to improve the machined surface quality. Every care against the hazard of fire must be taken when using kerosene and the light oils.

2. In machining **brass,** which shows no change in cutting forces with various cutting fluids, it is advisable to apply the cutting fluid to function as a coolant. Inasmuch as most free-cutting brass is machined in automatic screw machines, an oil is advisable to lubricate the moving parts of the machine and serve as a cutting fluid. A paraffin or light mineral oil may suffice, or the light mineral oil mixed with 10 per cent fatty oil may be used to advantage. **Bronze** and **copper** are more often machined with the mixed mineral-lard oil.

3. **Cast iron** is generally turned dry, as even water compounds tend to collect the chips in the form of mud in the machines. If chip separators are provided, water compounds, such as emulsions, increase tool life or permit higher cutting speeds with both high speed steel and sintered-carbide tools. Large volumes should be used. In grinding it is common practice to use water compounds or weak emulsions. In tapping, emulsions may be used but better results are obtained with sulphurized oil or white lead. Cutting fluids are discussed for each material under the various processes.

4. **Magnesium** and its alloys are usually machined with a very low-viscosity mineral oil, such as mineral seal oil, except where it is desirable to machine dry. Water compounds should not be used, as they create a serious fire hazard. A supply of powdered asbestos or graphite or cast-iron chips should be kept handy to smother a fire, just in case. A powdered extinguisher, known as G-1, is marketed by the Pyrene Co.; it was developed jointly by the Pyrene Co. and

the Dow Chemical Co. Tools should be kept sharp to avoid sparks, and heavy feeds should be used, as thin chips burn more readily. Chips should not be permitted to accumulate on the machine.

5. In turning **Monel** metal, it has been found that an emulsion gives a slightly longer tool life than a sulphurized mineral oil. The latter, however, produces broken-up chips, which in many instances are desirable.

6. **Steel** is machined under a wide variety of conditions. Cold-finished bars are usually machined in screw machines or automatics where light mineral oil, a mineral-lard oil, or sulphurized mineral oil is most satisfactory. Castings and large parts may be machined with emulsions, which are often very satisfactory and of low cost. Threading, drilling, broaching, and other slow-speed operations usually require a lubricating oil, such as a mixed or sulphurized oil.

7. **Zinc,** usually in the form of zinc die castings, may be drilled, threaded, turned, and milled with water emulsions. The parts should then be washed in an alkaline cleaner, rinsed in hot and cold water, and dried.

Storage and Circulation of Cutting Fluids

Cutting fluids are not used in many metal-cutting operations for the reason that the machine tool is not equipped with the necessary facilities required to circulate the liquid to and from the tool. The older job-shop machines are frequently provided with a drip can having a capacity of 2–4 qt so that, when desired, the cutting fluid may drip or flow in a very small stream onto the work and cutter and be collected in the drip pan or on the table. This is an inexpensive accessory and does furnish a means for some lubrication and cooling. A cutting fluid supplied from the drip can or from an oil can or wet brush frequently improves the performance of the tools used, such as in tapping by hand or power, threading in a lathe, or in light milling operations.

The storage, filtration, and circulation of cutting fluids receive a great deal of attention in the design of modern production machines. Even machines of semiproduction and toolroom types now either are equipped with a storage and circulating system or are so designed that one may be added conveniently. The modern machine has ample storage space, usually in the base or lower part of the column. A gear- or centrifugal-type pump delivers the liquid to the cutter. The cutting fluid, to be most effective, should be distributed in a large volume directly on the work ahead of the cutter. Frequently the cutter itself is flooded. The larger the volume and velocity of application, the better the cooling effect and the quality of finish obtained The power, too, is reduced with the greater quantities of cutting fluid used. From 3 to 5 gal per min at a temperature of 70–85° F per single-point tool is desirable. Frequently, in multiple-turning and milling operations, 40–60 gal of liquid flood the cutter each minute.

When cutting steel with sintered-carbide tools, it has been found especially beneficial to apply the liquid between the work and tool flank in large quantities at a constant rate.

Large settling tanks should be provided in these installations so that the sediment and fine chips in the oil may settle out before it is recirculated. The liquid often is filtered or passed through a magnetic separator as it flows by gravity from the cutter back to the storage tank, so as to remove small chips and foreign matter. The low-cost emulsions can be changed every few days, but the more expensive oils must be treated carefully. The oils from the self-contained units are removed from the machine to be filtered and sterilized before being used again. In large production, the chips from the machines are placed in a centrifugal extractor to reclaim the oil, which is then treated and again put in service.

Frequently in large-production shops a continuous system for circulating, purifying, and filtering the cutting fluid is provided so that the liquid may be delivered through pipes to a whole battery of machines. These systems may have filtration or centrifuging devices for cleaning the liquid each time it is circulated. Cutting fluids may become contaminated by picking up lubricating oil, slushing grease on the machine or stock, dirt and filth from handling, vapors from the atmosphere, etc. Frequent change or treatment of inexpensive water emulsions and solutions is desirable. The liquid may also be sterilized at intervals by heating it to the pasteurizing temperature of 140° F for not less than 20 min. Cleanliness of the cutting fluid, machine, and operator is imperative if contamination is to be avoided. Frequently disinfectants, such as crude carbolic acid (1 part in 500 of liquid), or USP cresol (1 part in 1,000), are added.

The Selection and Use of Cutting Fluids

In all cases where equipment permits, a relatively large quantity of cutting fluid directed on the work and cutter is advisable. The selection of the best type and quality, however, depends upon the actual operating conditions and involves the type of machine, storage, metal-cutting process, metal cut, tool material, and specific operation. With the central storage system, only one quality of cutting fluid is available for circulation to all machines in the battery served. The machine with self-contained storage permits use of a specialized type.

There appears to be no fixed rule for the selection of a cutting fluid for commercial use, and practice varies widely. Frequently any one of several will serve adequately. One may be found to work satisfactorily on a difficult job, with no adequate explanation, even after others have failed. The performance of cutting fluids does not follow the results of tests with them as lubricants, and data of specific heat and thermal conductivity for the various types are lacking. The type of machine used, or the type of operation, has a bearing on the selection. In turning, drilling, threading, reaming, milling, sawing, gear shaping or hobbing, broaching, grinding or honing, different factors arise which may indicate the need of cooling or lubrication, or the superfluity of lubrication.

Oils improve surface quality when the cutting speeds are low, Fig. VII-24, and they help remove chips from the chip space of broaches, taps, dies, drills, and saws. Any of these cuts may be heavy for roughing or light for finishing. At high speeds the water emulsions and low-viscosity oils function better. The sulphurized and fatty oils are more effective on metals of greater toughness and for finishing cuts.

The setup on a screw machine or turret lathe may combine several types of cuts (involving roughing and finishing), such as turning, drilling, reaming, and threading, so that the cutting fluids must be selected for the most important feature. The cutting fluid may flood the spindles and moving surfaces of the automatic screw machine and, therefore, must possess good lubricating properties. Sulphurized oils should not be used on machines with bronze spindle bushings. For general grinding, water emulsions or solutions are satisfactory. For high-precision thread and form grinding, low-viscosity sulphurized oils are used.

Water solutions give an increase in cutting speed of 10–30 per cent over dry cutting. Water emulsions are next in effectiveness, with the oils giving 5–15 per cent greater speeds than dry cutting. These values correspond to 100–2,000 per cent increase in tool life, Fig. VII-16. The effect of cutting fluids on tool life, force, power, etc., is discussed in connection with various types of tools and machines in the following pages. Types of cutting fluids are recommended for turning various metals in Table VII-2 (" Cutting Fluids — Their Use Surveyed," *Metal Progress*, June, 1938, p. 584). Other specific recommendations are given for various processes in following chapters.

QUESTIONS

1. What is meant by a cutting fluid?
2. What is meant by a lubricant?
3. Explain the difference in performance between a lubricant as used on drawing dies and a cutting fluid as used on a cutting tool.
4. What are the factors which enter into the best conditions for metal cutting?
5. What are the purposes of a cutting fluid?

6. Name twelve properties desired in any given cutting fluid.

7. Classify cutting fluids.

8. Explain the difference between a sulphurized mineral oil and a sulphurized fixed-oil base.

9. What would you consider the two best types of cutting fluids to standardize on if you were operating a small plant and wanted to use but two types of cutting fluids?

10. What are the advantages of the plain mineral oils over the fixed oils?

11. In operating an automatic screw machine, which types of oils would you use when cutting (*a*) free-cutting brass; (*b*) free-cutting Bessemer screw-stock steel; (*c*) an alloy steel, such as SAE 2330?

12. Compare the virtues of the central storage system for cutting fluids with those of the self-contained type.

13. What is the practice of using cutting fluids when machining cast iron?

14. What care should be taken to prevent infection from cutting fluids?

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CHAPTER VII

MACHINABILITY — SINGLE-POINT TOOLS

Definition of Machinability

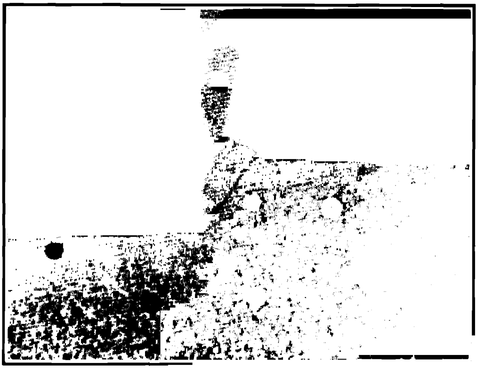
By machinability is meant the response of a metal to machining. This involves the performance of the cutting tool and usually the assistance of a cutting fluid to facilitate the operation. Good machinability implies satisfactory results in machining and is manifest in one or several results, as follows:

(*a*) Long tool life for a given cutting speed, or a high cutting speed for a specific tool life, or uniformity in performance based on cutting speed and tool life.
(*b*) High surface quality of the machined surface.
(*c*) Well-broken-up chips for easy disposal.
(*d*) Low power consumption in removing a given quantity of material.
(*e*) Uniformity in dimensional accuracy of successive parts.
(*f*) Maximum metal removal per tool grind.
(*g*) Removal of each unit of metal at the lowest over-all cost, etc.

The performance of the cutting tool is influenced by its shape, the material cut, the cutting fluid, and the conditions of operation. Also the machinability of the metal is dependent to a large degree upon the tool doing the cutting, the fluid applied, and other influences such as its chemical analysis, hardness, and metallurgical structure, size of cut, and all factors having a bearing on the process. The performance of a cutting fluid is definitely associated with the manner of application, the material to be cut, the type and shape of tool, the cutting speed, and size of cut.

Machinability is not a basic standard, but is relative. The rated machinability of two or more metals (or tools or cutting fluids) being compared may vary for different processes of cutting, such as heavy turning, light turning, forming, milling, drilling, sawing, broaching, or grinding.

Good machinability indicates satisfactory tool life, good machined surface quality, low force, energy, or power, well-broken-up chips, and consistent dimensional accuracy, either collectively or singly, depending upon which of these objectives is the one most desired. Many times one or more objectives must be sacrificed to obtain others. These objectives are not necessarily compatible, so that each machining job must be set up with the most favorable cutting tools, materials, and cutting fluids. There is no single conclusive manner of determining the machinability rating of materials cut, cutting tools, or cutting fluids. One type of material of a number, for example, may give the best tool life, but another may provide better surface quality and a third the best-broken-up chips, etc. By keeping two of the elements, such as tools and cutting fluid, constant, and varying the third, metal cut, the optimum combination can be determined as it affects tool life, surface finish, cutting forces, form of chip, and uniform dimensional accuracy, etc.



After E. G. Herbert.

FIG. 1. Chip Formation of Free-Cutting Brass Rod.

This shows little distortion of the structure of the metal formed into chips. The time hardness of the uncut metal was about 19, that immediately ahead of the last chip removed 24, and that of the chip just separated 25.8. The increase in hardness induced by the tool is 36 per cent. (10 X)

Tool Cutting Action and Chip Formation

Chips formed of brittle metals: When cutting brittle metals like cast iron and free-cutting brass, Figs. 1 and 2, most of the chip is removed with little distortion by a pressure on the tool face back of the cutting edge. Brass chips usually are compressed and remain in fairly equal sizes, whereas cast-iron chips are broken into particles of various shapes and sizes from lumps to dust. In the case of cast iron, metal is pushed off by the pressure built up on the tool face, and the cutting edge of the tool scrapes over the machined surface, removing the irregularities. Because of this method of cutting and the abrasive character of the metal, the tools fail by abrasion on the flank between the tool and work.

Chips formed of ductile metals: Chips of ductile metals are removed by varying proportions of shear, tear, and flow. This results in three general types or shapes of chips, such as the discontinuous or segmental, continuous with an appreciable built-up edge, and continuous with little or no built-up edge.

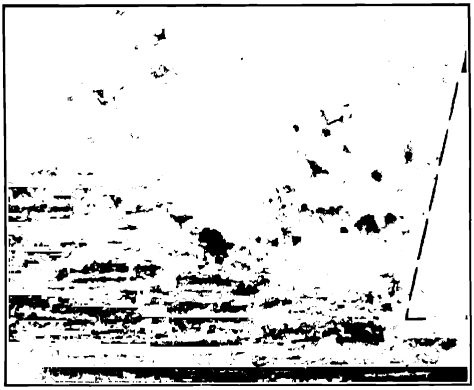


FIG. 2. A 15-deg Back-Rake Angle Planer Tool Indicated at the Right Removing a Chip 0.020 in. in Depth from Cast Iron; the Brittle Nature of the Material is Indicated. (55×)

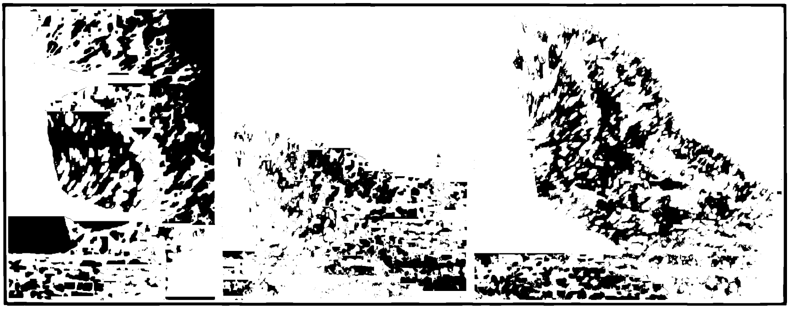


FIG. 3. Formation of the Segmental or Discontinuous Type Chip When Removing Annealed Low-Carbon Steel with an End-Cutting Shaper Tool Having 15-deg Back Rake with a Depth of Cut of 0.020 in., When Making 9 Strokes per Minute, Each Stroke $6\frac{1}{2}$ in. Long, Average Cutting Speed 10 fpm.

At the left the cutting edge is just picking up the chip; in the center it has progressed; and at the right a complete element of the chip is formed on the tool face, which is being sheared off, after which a second element will be started.

At very low speeds (usually less than 30 fpm), the chip is removed by shear and tear to form discontinuous or segmental chips shown in Fig. 3. At average cutting speeds for high speed steel tools (approximately 35–200 fpm) a built-up edge is formed just after the cut is started, as shown for aluminum in Fig. 4, and for steel in Fig. 5. It appears that, when the cut is started in ductile metals, the material bearing on the tool face is trapped and compressed against the face of the tool by the frictional force on the tool face and the compressing or shearing force. This metal becomes the built-up edge which is forced into that being cut as the tool advances. Figure 5 shows that the cutting edge of the tool does little more than support the built-up edge which in itself is the actual medium by which the chip is removed from the parent metal. Figure 6 also shows the built-up edge supported on the ridge of low rake while the secondary high rake allows the chip to escape with little friction on the tool face.

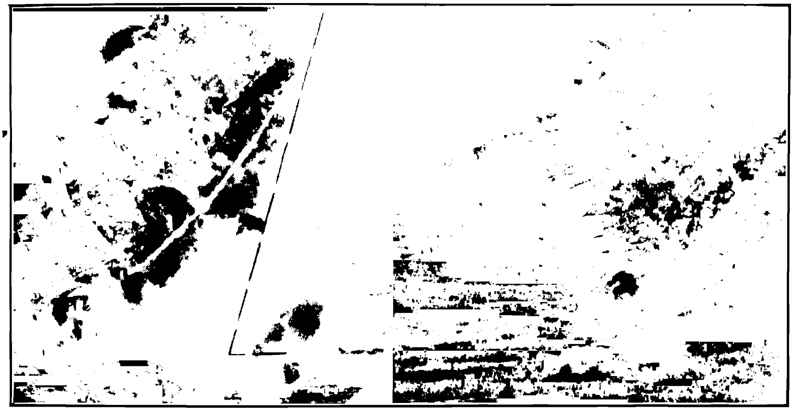


FIG. 4. The Built-Up Edge of Cast-Aluminum Alloy (SAE 12) on Planer Tools.

The depth of cut was 0.010 in., and the cutting speed very slow. Both tools were lapped to have smooth and keen cutting edges.

The tool at the left had a 15-deg back-rake angle. The built-up nose magnified 50 times was photographed after the cutting tool had cut for $3\frac{1}{8}$ in. When the cutting was stopped, the tool was at the position indicated by the dashed lines, but is shown withdrawn. The height of the built-up nose is about equal to the thickness of the deformed chip. The slope of the built-up nose at the point is slightly less than 45 deg. At the right is shown a 45-deg back-rake tool and the built-up nose magnified 70 times. The small built-up edge is indicated by the curved face of the tool, the angle of which at the forward end appears to be about equal to that shown for the 15-deg tool.

The size and shape of the built-up edge vary with the material cut, the tool shape, the size of cut, the cutting fluid, and the cutting speed.

The built-up edge appears to be a rather permanent structure as long as the cut is continuous at relatively high speeds. Portions of it may slough off and be carried away on the underside of the chip, and frequently portions of it pass between tool flank and work and adhere to the machined surface in the form of small saw-tooth edges, shown in Figs. 5 and 6. This built-up edge forms a new rake angle apparently optimum for each material and cutting condition, Fig. 4.

At very high speeds, usually associated with sintered-carbide tools, the built-up edge is very small or nonexistent, as illustrated in Fig. 8, and a smooth machined surface results. The thinner the chip, the smaller is the built-up edge, and the cutting edge leaves a smoother finished surface.

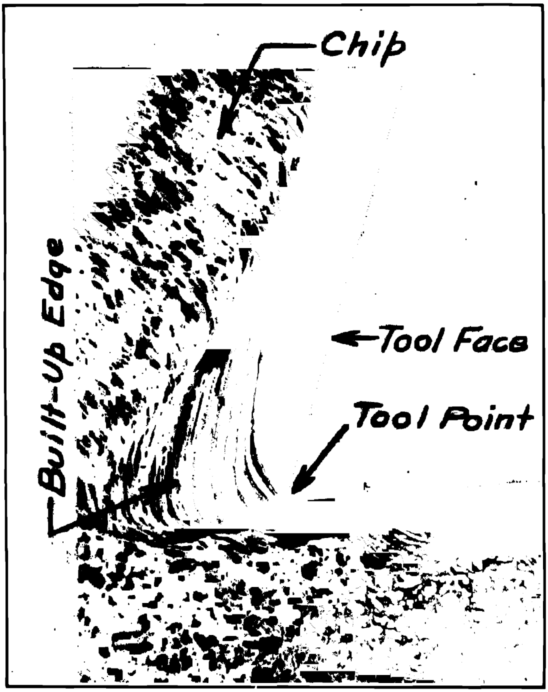
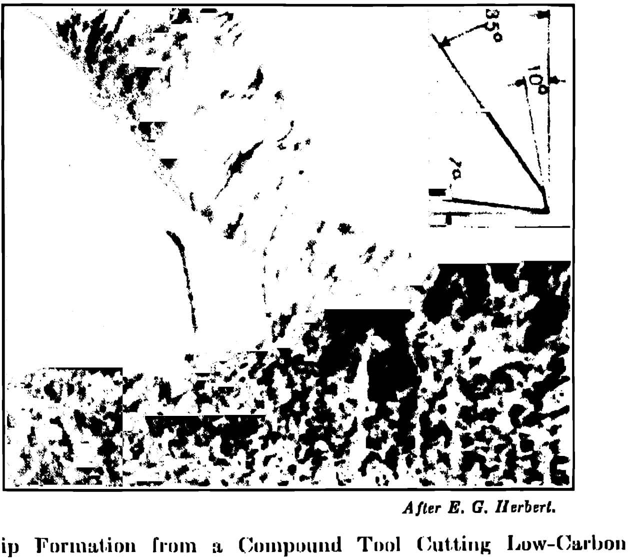


FIG. 5. A Built-Up Edge Formed in Annealed Low-Carbon Steel by a Tool with a 15-deg Rake Operating at a Depth of Cut of 0.020 in. and a Cutting Speed of 120 fpm.

A mineral oil containing sulphur and chlorine was used as a cutting fluid. (25 X)

The **work hardening** of the material cut is a definite factor in the machining process. Figures 7 and 8 show the hardness at several points on the undisturbed metal, at the machined surface in the chip and in the built-up edge. There is less work hardening in the continuous chip with no built-up edge, and yet the cutting force required to remove the chip under both conditions is practically the same.

Chips formed by three identical tools when the depth of cut is constant, but with **different feeds,** are shown in Fig. 9. The condition of the tool face caused by the chips sliding over the built-up edge and tool face also may be noted. Figure 10 shows the chip formed when the feed is constant, but with different depths of cut. Grooving on the tool face has already started.



After E. G. Herbert.

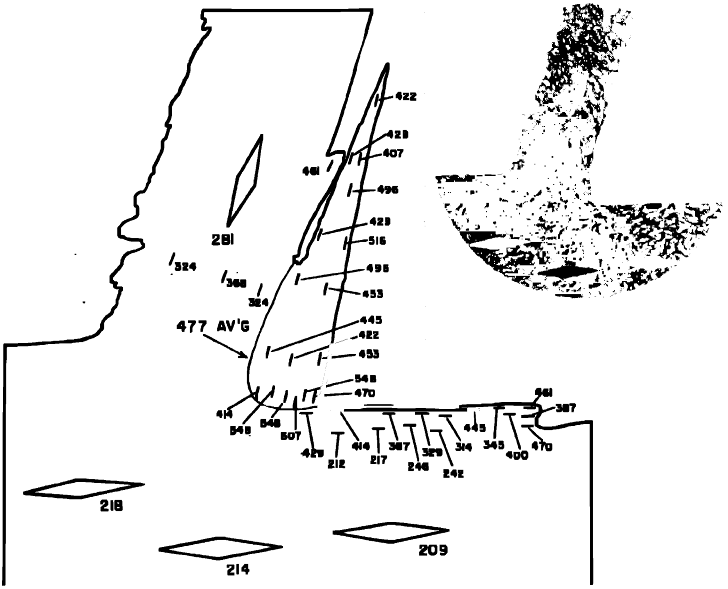
FIG. 6. Chip Formation from a Compound Tool Cutting Low-Carbon Steel.

The tool had 7-deg relief, a ridge having 10-deg back rake, and 0.017-in. width, and then a secondary 35-deg back-rake angle. The depth of cut is approximately 0.020 in. The cutting action and thickness of chip are quite normal. A permanent built-up edge is formed of characteristic layered structure. It is hooked over the edge of the tool so as to protect it completely from contact with the work. When the width of the ridge back of the cutting edge is more than the depth, the resistance to cutting and the generation of heat are increased, because of greater distortion and work hardening of the chip. (20 ×) With carbide tools the rake of the ridge may be minus 5–10 deg for longer tool life.

The **progress of tool wear** can be estimated readily from the color, shape, and size of the chip produced. In turning ductile metals, such as steel, the chips produced at first are long, quite straight or slightly coiled, and regular. As the tool wear progresses, the chips become more coiled, and as the cutting edge breaks down, the chips become irregular in section and dark blue in color. The machined surface or the shoulder of cut becomes burnished in ridges and rougher in general. The color indicates the development of excessive heat, even though the tool is newly ground and has cut but a small part of its total life. Such a chip is illustrated at 1 in Fig. 11. After the groove is formed in the face of the tool, the chips become coiled, either in short spiral forms or long helical forms of small diameter. In this connection the chip is no longer colored and the tool cuts for the greatest length of time. Chips 1–5, inclusive, illustrate this transition.

As the groove wears larger in the face of the tool and toward the cutting edge, the chip again becomes slightly blued just before failure occurs, owing apparently to greater chip distortion.

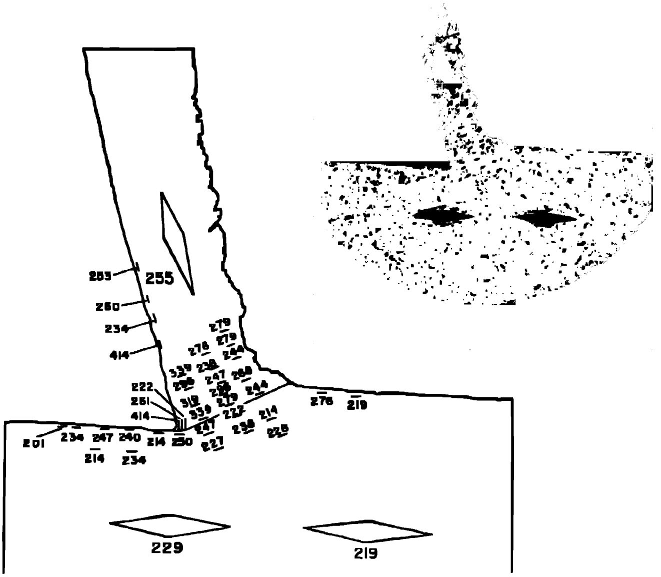
Chatter: Frequently in the formation of chips, high-frequency vibrations occur when the tool or work is not supported rigidly, because of the sliding of the chip elements into sections, or because of the periodic sloughing off of the built-up edge. These vibrations may set up a natural period of vibration of the tool, the work, or even the whole machine, which may become very objectionable because of noise, poor surface finish, gear knocking, and possible damage to the machine. Rigidity of work and tools or change in feed or depth of cut, or in tool shape, may remove the cause of vibration. Long thin chips, such as those made with a large nose-radius tool or with a long straight-cutting-edge tool, increase the probability of chatter.



Courtesy Cincinnati Milling Machine Co.; M. E. Merchant and N. Zlatin.

FIG. 7. A Chip Formed by Built-Up Edge When Broaching SAE 1112 Steel at 40 fpm with a High Speed Steel Tool with 15-deg Rake Angle.

Knoop numbers obtained on a Tukon hardness tester, of the original metal; the chip and the built-up edge show induced hardness in the last two as a result of metal deformation. Readings are approximately equal to Brinell numbers. ("Distribution of Hardness in Chips and Machined Surfaces," *Trans. ASME*, 1947.)



Courtesy Cincinnati Milling Machine Co.; M. E. Merchant and N. Zlatin.

FIG. 8. A Chip Formed with No Apparent Built-Up Edge by Milling SAE 1112 Steel at 780 fpm with Sintered-Carbide Tool Having 10-deg Rake Angle.

Knoop hardness values at various locations are shown. These are lower on the smooth machined surface than in Fig. 7.

Machinability of Cutting Tools

Tool efficiency: A tool is efficient **first,** according to the length of time that it will cut a given chip at a certain speed per grind (tool life or endurance); **second,** according to the power consumed by the tool in removing the metal; **third,** by the finish it produces; and **fourth,** by the shape of chip.

Methods of tool failure: The failure of turning tools may be the result of:

1. Abrasion on the flank below the active cutting edge, as when carbon-steel, high speed steel, or sintered-carbide tools are turning cast iron and as when carbon-steel tools are turning steel.

2. The development by abrasion of a crater on the tool face just back of the cutting edge. As this depression increases in size, its edge approaches the cutting edge. The included metal eventually breaks off, causing sudden tool failure. This type of failure occurs when high speed steel, Stellite, or sintered-carbide tools turn ductile metals, as illustrated at the left in Fig. 12.

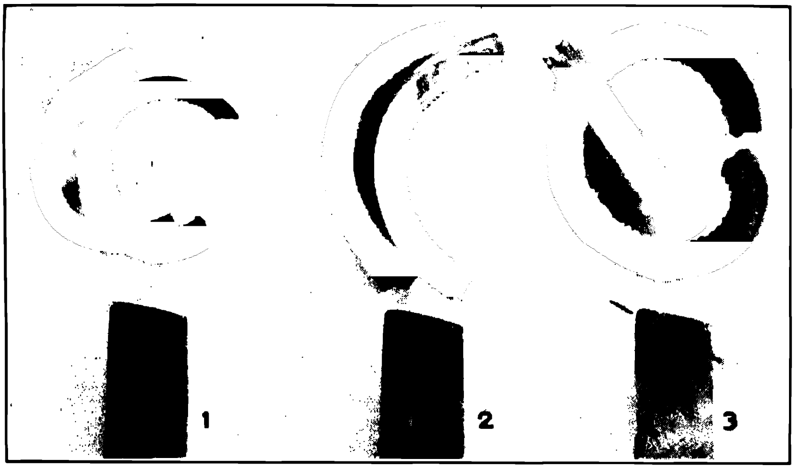


FIG. 9. Influence of Variable Feed on Chip Formation of SAE 1045 Steel.

The tools of high speed steel each have 8-deg back rake, 14-deg side rake, and 90-deg setting angle, and a nose radius of $\frac{1}{32}$ in. The rubbed face of the tool and form of chip for three turning cuts each $\frac{1}{8}$ in. in depth but 0.0104 in., 0.0204 in., and 0.0416 in. feed per rev, respectively, are shown from left to right. Both sides of chips are shown as produced 1 min after each tool started to cut at a speed of 85 fpm.

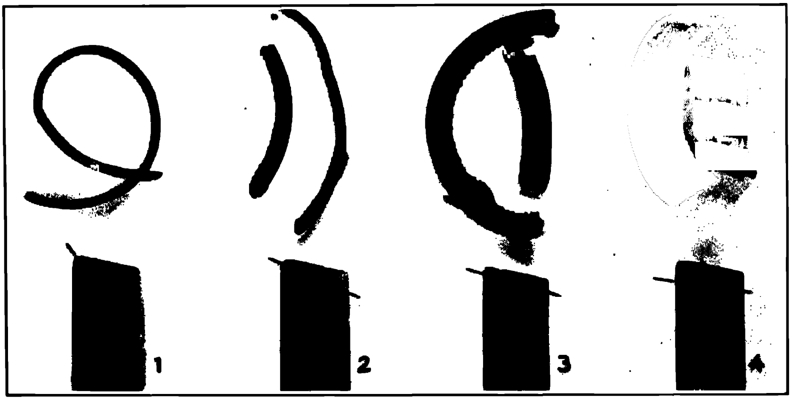


FIG. 10. Influence of Variable Depth of Cut on Chip Formation of SAE 1045 Steel.

The four tools similar to those in Fig. 9 produced chips 2 min after starting to cut at 80 fpm and a constant feed of 0.0204 ipr but at depths of cut from left to right of 0.0312, 0.0625, 0.125, and 0.250 in., respectively. Cupping of each tool has started, and parts of the built-up edge are seen. The direction of flow of chip is indicated and is seen to swing to the right as the depth of cut is increased.

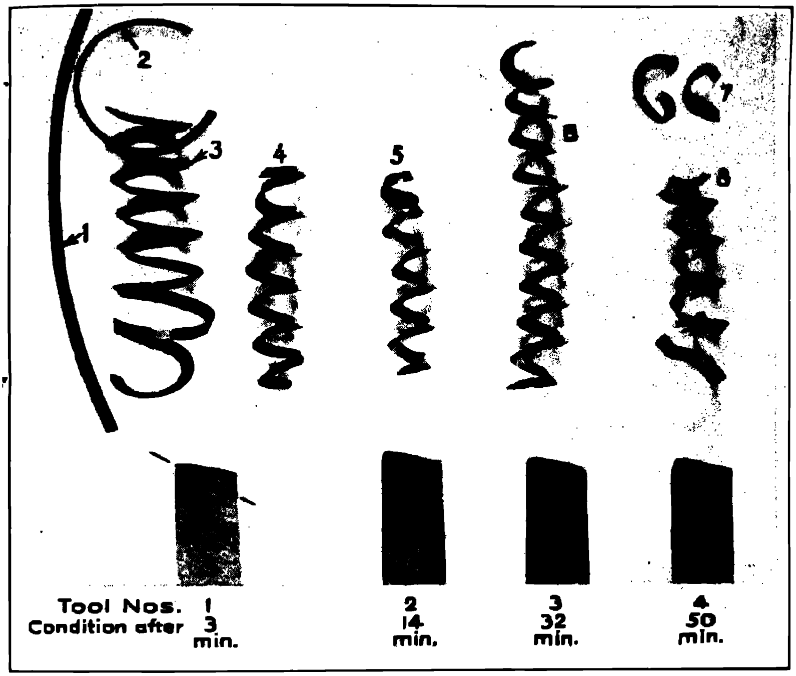


Fig. 11. Chip Formation as Influenced by Tool Wear When Cutting SAE 1045 Steel.

Four tools similar to those of Fig. 9 show progressive wear, together with the formation of chips for the different degrees of wear. The cutting speed was approximately 160 fpm, the depth of cut 1/16 in., and the feed 0.0104 ipr.

Chips 1 to 4 were those first produced by tool No. 1 during the first 3 min of cutting. The condition of tool No. 1 is shown at the end of the 3-min cutting period. Chip No. 5 is that produced by the well-grooved tool No. 2 after cutting for 14 min. Chip No. 6 is that produced by tool No. 3 after cutting for 32 min, and appears quite similar to chip No. 5. Chips No. 7 are those produced by tool No. 4 after cutting for 40 min. Chip No. 8 was produced by tool No. 4 shortly before failure occurred. The tool point failed as the groove wore forward to the cutting edge.

3. A combination of flank abrasion and cratering as shown at the right in Fig. 12 and in Fig. 13.

4. The spalling or crumbling of the cutting edge, as when cutting extremely hard material.

5. The loss of hardness because of excessive heat generated at the cutting edge, as when turning at extremely high speeds.

6. Fracture because of excessive loads. While the size of a tool has little influence on tool life, a ¼-in.-sq tool bit will have about the same tool life as one ¾ in. sq, but it must be strong enough not to break under cut.

Application of Various Tool Materials

Carbon tool steel is used for all types of cutting tools for light or low-temperature work. It provides keen cutting edges desired for finishing tools on screw machines, particularly when machining the freer-cutting metals.

The 18–4–1 (W-Cr-Va) and Mo-Max (W-Mo-Cr-Va) types of high speed steels are recommended for general use on all-round work and for continuous-chip materials, such as SAE 1112, C1137 (old X1335), and 1010–1040, by the Gorham Tool Co. The higher-carbon steels and tougher alloy steels, such as SAE 1040–1095, 1330, the 32, 33, 41, and 51 series, and the 52100, call for the use of 18–4–2 or the Mo-Max high speed steels. The SAE series 23, 31, and 61 steels machine best with the cobalt-bearing analysis of tungsten and molybdenum steels. Stainless steels, cast steels, and manganese steels seem to be machined most economically with the 8 or 12 per cent cobalt-tungsten steel or the 8 per cent cobalt-molybdenum high speed steel.

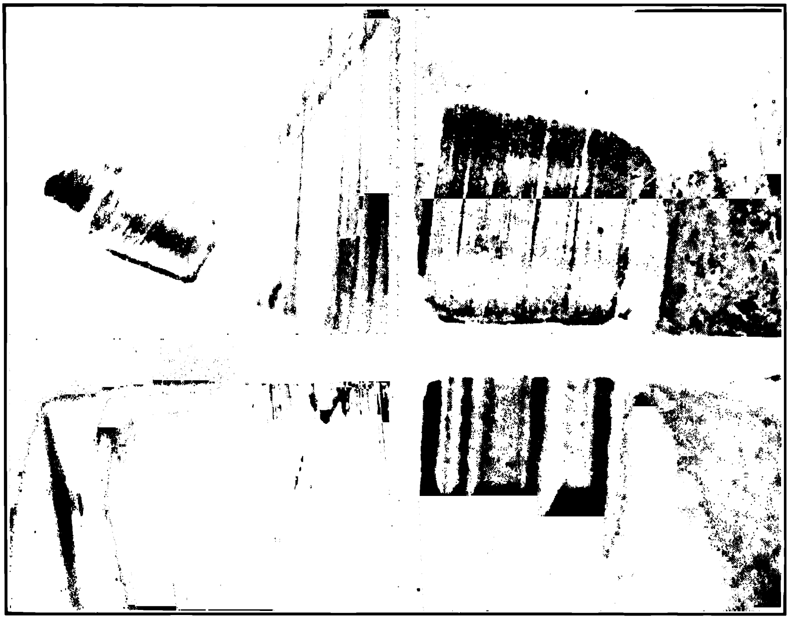


FIG. 12. The Nature of Face and Flank Wear on Tools of High Speed Steel (*Left*) and Sintered Carbide (*Right*).

At the left, a photograph of a high speed steel tool showing normal flank wear below and cupping of the face above, together with nose breakdown when turning a Monel metal with an emulsion. Depth of cut 0.100 in.; feed 0.0127 in.; width of ridge supporting built-up edge 0.0004 in.; width of crater from the ridge 0.05 in.; and width of the normal land worn on the flank 0.004 in.

At the right are shown the cupped surface above and the abraded flank below of a sintered-carbide tool after turning soft steel. The newly formed cutting edge is irregular but continuous. The tool is registered as failed because of the 0.030 in. average flank wear.

For abrasive materials, such as the cast-iron and nonferrous group, where tools usually fail by flank abrasion rather than cupping, the 18–4–3¼ analysis has proved to be best.

The **cast nonferrous** tool materials, such as Stellite, will cut at a cherry-red temperature, at speeds 50–100 per cent above those for high speed steel but below those for sintered carbides. They are brittle and therefore operate best when taking light cuts in low-carbon steel, malleable cast iron, gray iron, bronze, steel castings, hard rubber, and fiber. Chip breakers work well in these tools which may be of the solid or tipped type. Star-J metal and Crobalt A are used for abrasive materials such as cast iron and plastics, while Stellite 98 M 2 and Crobalt 138 are for the continuous chip metals, steel, etc.

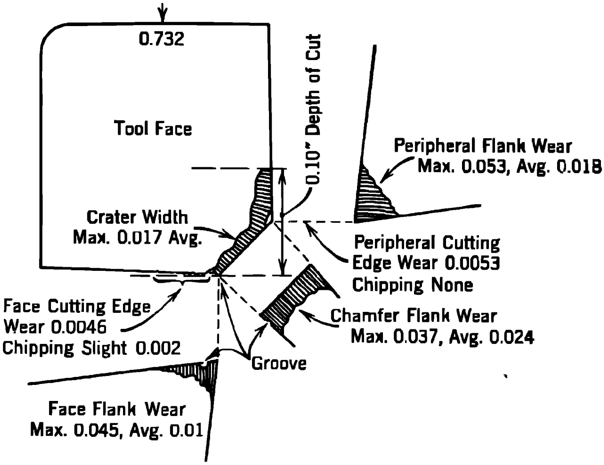


FIG. 13. The Nature of Wear on a Sintered-Carbide-Tipped, Face-Milling-Cutter Tooth.

The cupping of 0.017 in. average width on the face back of the chamfer and peripheral cutting edge, chipping of 0.002 in. on the face cutting edge, and abrasive wear averaging 0.030 in. on the face flank, chamfer flank, and peripheral flank, with a maximum value of 0.053 in. on the corner, are shown. This tooth was of sintered carbide K2S having tool angles of 7, 7, 6, 6, 2, 0, 0.070 in. at 45-deg chamfer on a 9-in.-diam. face mill facing 20,000 psi cast iron 4 in. wide with a depth of 0.100 in. and a feed per tooth of 0.01 in. at 506 fpm. The machine cutting time was 48.8 min, but the actual cutting time was 7.07 min.

Sintered tungsten carbide with 3–8 per cent of cobalt is used for machining cast iron, brass, bronze, rubber, paper, plastics, etc., which cause the tool to fail by flank abrasion. The lower cobalt gives a harder, less ductile tool which better resists abrasion, as in light, high-speed cuts in hard cast iron. Cobalt up to 13 per cent gives a tougher metal better for heavy cuts in iron and steel castings, or for interrupted cuts.

Titanium carbide and tantalum carbide, alone or in combination, are added to the tungsten carbide and a cobalt binder to form sintered-carbide compositions suitable for machining those **metals such as steel** which produce a built-up edge, or long continuous chips at high speed, and cause the tools to fail by cratering on the face and abrasion on the flank. The tool should be removed for regrinding when the width of the flank abrasion has an average value of about 0.030 in., so that only a small amount of metal has to be ground off the face and flank. These sintered carbides, known as Carboloy, Firthite, Kennametal, etc., are made in numerous grades of various designations for specific purposes, as recommended in Table 1.

Diamonds are used generally in precision machining where the material is too hard or too abrasive for steel or Stellite tools, or where greater accuracy or better finish is wanted on softer metals, such as on aluminum piston-pin holes and bronze bushings. For turning tools, the diamonds are ground with a side-cutting-edge angle of 45 deg, an end-cutting-edge angle of 2 deg, end-cutting relief from 2 to 5 deg, with side relief up to 10 deg. No side and little back rake is provided. Diamond tools, clamped, brazed, or cast into steel holders, usually operate at very high speeds and fine feeds, such as from 600 fpm in steel to 1,100 or more in the nonferrous metals with feeds of 0.001–0.003 in. and a depth of cut from 0.004 to 0.020 in. No cutting fluid is needed (*Machinery*, January, 1930, p. 401, and March, 1930, p. 561). **Sapphire**-tipped tools are being used for precision machining in the field between those covered by sintered carbides and diamonds.

Tool shape versus performance: The rake, relief, nose radius, side- and end-cutting-edge angles each influence tool performance to a considerable extent. Therefore, their values should be selected with care.

Rake: The rake or slope of the tool face forces the chip to slide off in a convenient direction. It reduces the cutting force, which is from 230,000 to 500,000 psi of cut for steel, and, up to a certain value, increases tool life. Back rake on a side-cutting tool is of less importance than side rake. It usually controls the direction of chip flow.

In choosing between side rake and back rake to produce sufficiently acute cutting angle, the following considerations, given in order of importance, call for a steep side rake and are, therefore, opposed to a steep back rake: (*a*) with side rake, the tool can be ground many times more without weakening it; (*b*) the chip runs off sidewise and does

TABLE 1. SINTERED-CARBIDE COMPARISON CHART OF STANDARD GRADES

For Use as a Guide in Selecting Appropriate Grade for Tools

Code	Use	Carboloy	Firthite	Vascoloy-Ramet	Kennametal	Willey	Carmet	Talide	Wesson
C-1	Rough cuts on cast iron and nonferrous materials.	44A	H	2A68	K6	E8	CA3	C80	GS
C-2	General purpose on cast iron, nonferrous metals, and stainless steels, also general reamer use.	883	HA	2A5	K6	E6	CA4	C91	G1
C-3	Finishing cast iron and nonferrous metals.	905	HE	2A7	K8	E5	CA7	C93	GA
C-4	Precision boring cast iron and nonferrous metals.	999	HF	2A7	K8	E3	CA8	C93	GF
C-5	Rough cuts on steel.	370, 78B	T-04	EE	K2S, KM	945	CA5	S88	WS
C-6	General purpose on steel.	370, 78B, 350	TA	EM	K2S	710	CA1	S90	WM
C-7	Finish cuts on steel.	350, 78	T-16	E	K3H	606	CA2	S92	WH
C-8	Precision boring and light finishing steel.	831	T-31	EH	K5H	509	CA6	S92	WH
C-9	Wearmaterials;centers, rest blades, gages.	44A, 883	HA	2A5	K8	E-6	CA10	C89	G1

not strike the tool post or clamps; (*c*) as the pressure of the chip tends to deflect the tool in one direction, a steep side rake tends to correct this by bringing the resultant line of pressure within the base of the tool; (*d*) the tool is easier to feed.

A tool is efficient when it removes a relatively large amount of metal per grind or when it removes metal with a relatively low power consumption. The smaller the cutting angle, Fig. V-5, the more efficient from a power standpoint is the cutting action, but the sooner the sharp edge will fail. The ratio of final to original thickness of chip will be low. The more blunt the lip angle, the more it is reinforced to withstand the cutting force and carry away the heat generated, but it will push the metal off with excessive shear rather than tear it off by a wedging action. The chip ratio will be high.

The harder the metal, the blunter should be the cutting angle. For high speed steel tools turning hard steel and cast iron, a rake of 5–15 deg is best for general results as maximum speed for specific tool life is obtained. For soft steels, this angle should be increased to 20–30 deg. Tools for cutting chilled iron should have a rake angle of 0–4 deg, while those for cutting brass should have neither back nor side rake. This is to reinforce the lip to prevent spalling in the case of chilled iron and to prevent digging in or chatter in the case of brass. Tools with only small back and side rake are used to machine the free-cutting metals, but for the annealed soft metals, such as aluminum, copper, and magnesium, appreciable rake is desired. See Table 2 for recommended tool shapes.

For Crobalt or Stellite tools, the rake angles are smaller and the face is made up of the harder surface of the cast metal, better to support the cutting edge with a large lip angle of the less ductile metal. See Figs. 14 and 15.

Sintered-carbide tools, strong in compression but less ductile than high speed steel, have rake angles more like those of Stellite than high speed steel.

For rough, heavy cuts, particularly intermittent ones, a negative back rake removes the initial impact load from the cutting edge. For roughing cuts on old machines, −2 to −4 deg back rake is recommended. For roughing cuts on shapers and planers, from −6 to −10 deg, on steel castings, −2 deg is recommended. The negative or low back-rake angle is compensated for with larger side-rake angles.

Relief angle: The relief angle below the cutting edge should be sufficient to prevent the flank from rubbing on the work. It should be sufficient on the feed side of the tool in lathe work to allow for the feed helix angle on the shoulder of the work. This is of great importance on work of small diameter, but is of no importance in straight-line cutting on the shaper and planer. For straight-line cutting, a relief angle of 4 deg is sufficient for most work, but for turning, 6 deg is more practical. In general, the relief angle should be small for hard metals and large for soft metals. For some metals, such as aluminum, magnesium, copper, and nickel, which may stick to the flank and produce a rough-machined surface, a greater relief angle should be provided. The value of the relief angle does not influence the force on the tool, but it should be as small as possible to increase the endurance of the tool. Carbide tools should be used with relief angles larger (7–9 deg) than those for high speed steel tools.

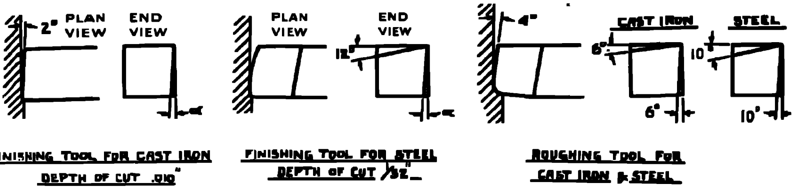


Fig. 14. Tool Shapes for Various Purposes as Ground from Bits of Cast Nonferrous Metal.

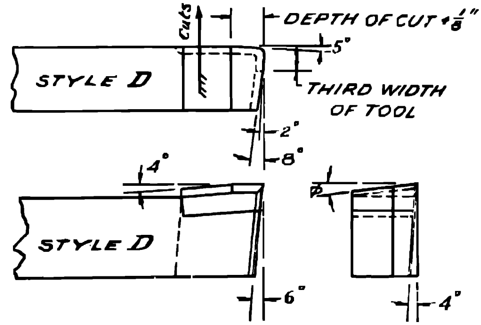


Fig. 15. A Stellite-Tipped Tool for General Use on Cast Iron and Steel.

Nose radius: Nose radius has a definite influence on the permissible cutting speed for a given tool life. For a 60-min tool life when turning SAE 2345 steel forgings annealed with $\frac{3}{8}$-in.-sq high speed steel bits having 8-deg back rake and 14-deg side rake, using a cut 0.100 in. deep and a feed of 0.0125 ipr, the cutting speed for the zero-inch radius tool was 74 fpm. This increased to 97 for $\frac{1}{32}$-in. radius, 106 for the $\frac{3}{64}$-, 138 for the $\frac{1}{8}$-, 151 for the $\frac{3}{16}$-, and 161 for the $\frac{1}{4}$-in. radius. This shows an over-all increase from 74 to 161 fpm, or 118 per cent.

For the above cut, a relation was found between the cutting speed V, the tool life T, and the radius R as follows:

$$VT^{0.0027} = 331\ R^{0.244}$$

The nose radius has little influence on the value of the cutting force. The larger radius, however, does give a smoother surface finish and longer tool life.

Side-cutting-edge angle: The side-cutting-edge angle of the tool has practically no effect on the value of the cutting force or power consumed for a given depth of cut and feed. Tool life is greatly increased, however, as the entering angle is reduced. For a 60-min tool life in annealed SAE 2345 steel, the cutting speeds for high speed steel tools having $\frac{3}{64}$-in. nose radius, 8-deg back rake, 14-deg side rake, and 0-deg side-cutting-edge angle were 107 fpm; 137 fpm for 30 deg; 149 fpm for 45 deg; and 158 fpm for 60 deg. The last is 48 per cent higher than the first. For the 0.100-in. depth of cut by 0.0125-in. feed in SAE 2345 steel, a relation between the cutting speed in feet per minute, V, the tool life in minutes, T, and the side-cutting-edge angle, a, was found to be

$$VT^{0.11} = 78\ (a + 15\ \text{deg})^{0.264}$$

Large side-cutting-edge angles are likely to cause the tool to chatter. The curved cutting-edge or large-nose-radius tool then may be used to vary the chip thickness. High speed steel tools cutting castings or scaled forgings should have 0-deg side-cutting-edge angle.

Frequently, the metal being cut is inclosed in a hard or tough skin, such as the chilled surface on cast iron, the decarburized surface of malleable iron castings, and the scaly skin of steel forgings. It is logical to assume that the shorter the length of cutting edge in contact with this hard skin, the less will be the damage done to the tool and the easier it will be to repair. Furthermore, thicker chips are formed under this condition, and the pressure of the chip back of the cutting edge on the tool face tends to break off the hard iron ahead of the cutting edge or produce a larger built-up edge of the ductile metals to protect the cutting edge. The shortest distance through the skin is at right angles to the surface; therefore, where the tool comes in contact with the skin, the cutting edge should follow that shortest distance as nearly as possible.

Cast nonferrous tools should have small side-cutting-edge angles, as shown in Fig. 14, so that the cutting edge is formed by the harder metal near the chilled surface. Sintered-carbide tools should have large side-cutting-edge angles even up to 60 deg. This, with small end-cutting-edge angles, increases the strength of the tool nose, reduces the thickness of the chip, and leads to longer tool life. The starting load is taken on the tip at a point back of the nose where the tool is stronger.

The **best tool shape** for each job is based on many factors as discussed above. The versatility of the tool, the metal being cut, and the size and shape of cut are factors which help to determine the tool shape. The side-cutting-edge angle should be large for steel, but small for cast iron. The back rake should be just enough to control chip flow. The side rake should be as large as permissible for good tool life. The nose radius, except on carbide tools, should be relatively large. The **end-cutting-edge angle** should be as small as convenient to give more metal back of the nose and cutting edge and to give a smoother machined surface. Small grooves or craters to form chip breakers are sometimes ground in the face of the tool parallel to and back of the cutting edge a distance equal approximately to half the feed, or a new face may be ground below the original. (See Chap. V.) Chip breakers of this type in high speed steel are apt to reduce the tool life to one-third of normal, unless they are correctly proportioned. Frequently chip breakers of abrasive-resistant metal, against which the chip impinges, are attached to the tool face. The Gould and Eberhardt Co. recommends shaper tools of a shape 5, 10, 4, 4, 4, 10, 1/8 for shaping cast iron; 0, 20, 4, 4, 4, 20, 1/8 for shaping soft steel; and −2½, 12, 1½, 3½, 2 deg 40 min, 20, 1/16 for hard steel.

Speeds and Feeds for Turning

If the tool life in turning with high speed steel tools is represented by 100 per cent, then, on approximately the same basis, carbon tool steel would rate 30–50 per cent, Stellite from 150 to 200 per cent, and sintered carbides from 300 to 1,000 per cent.

Commercial cutting speeds, cutting fluids, and tool shapes for high speed steel, Stellite, and sintered-carbide tools when turning a wide variety of materials are suggested in Table 2. The speeds may be higher if lighter cuts are made or cutting fluids are used, and reduced for heavier cuts.

Commercial cutting speeds to give a tool life of 90 min (V_{90}) for cast iron and steel are given in Tables 3 and 4 for Taylor high speed steel tools for various combinations of depth of cut and feed. The high speed steels of today are superior to and have a higher degree of "red hardness" than those of Taylor. The cast iron and steels are lower in strength than metals in current use. The data are complete

TABLE 2. RECOMMENDED TOOL SHAPES AND CUTTING SPEEDS FOR TURNING VARIOUS METALS WITH APPROXIMATELY 3/32-IN. DEPTH OF CUT AND 1/32-IN. FEED

Material Cut	Tools					Cutting Speed, fpm	Tool Life, min	Cutting Fluid Recommended†
	Tool Material	Angles, deg*			Nose Radius, in.			
		Back Rake	Side Rake	Relief				
Aluminum and alloys	h.s.s.	15	15–40	8–10	1/16	400–1,000		P + 0 or
	WC	10–20	10–20	8–10	1/16	1,000–3,000		Em + 10% K
Babbitt	Dia.		0	2–5		1,000		Em, K + 20% T
Bakelite, plastics, and hard rubber	h.s.s.	0	0	10–15	1/16	100		D
	WC	4–8	4–15	6–8	1/16	600		D
Brass	C.S.	0	0	6	1/16	200		MO,D
	h.s.s.	0	0	6	1/16	300		
	WC	0	4–14	6	1/32	700		
Bronze	h.s.s.	0	6	6	1/16	70		Em 1–5 or
	Stell.	0	6	6	1/16	219		MO
	WC	0	4–12	6	1/32	200–400		D
Bronze, silicon	h.s.s.	7–10	8–12	8–12	1/16	80		MO + 5% LO
Cast iron (medium)	h.s.s.	8	14	6	1/16 – 1/2	80	180	D, Em
	Stell.	0	6	6	1/16 – 1/8	200		
	WC	0–4	0–4	6–8	1/16 – 1/8	240–350	660	
Commutators (copper and mica plate)	h.s.s.	22	15	6–10	1/32	90		D
	WC	18	12	6–10	1/16	500–1,000		D
Copper, rolled	h.s.s.	20	30	8–10	1/8	80–150		Em, S MO
	WC	4	20	8–10	1/16	400 +		
Copper, cast	h.s.s.	6–20	10–30	8–18	1/8	200		Em, S MO
Magnesium and alloys	h.s.s.	0	12–15	9–12	1/8 – 1/4	400–3,000		MO, K, D‡
Malleable cast iron	h.s.s.	8	14–20	6	1/16	90		Em
	Stell.	0	6	6–8	1/16	188	188	
	WC	6	10	6	1/16	200 +	420	

Monel, cast	h.s.s.	8	14	6-13	3/16	60	60	Em, S MO
	WC	0	10	6	1/16	180	300	D
Monel, rolled	h.s.s.	8	14	6-12	3/16	70	60	Em, S MO
Semisteel	h.s.s.	8	14	6	1/8	80	120	D
	WC	0-4	5-10	6	1/16	200+	480	D
Steel (free-cutting) SAE B1112	h.s.s.	8	18	6	1/16	180		Em, MO LO, S MO
	Stell.	0	10	6	1/16	344+		
	WC	0	6	6		300-600		Em
Steel (low-carbon) SAE 1020, 1035	h.s.s.	8	22	6	1/16-1/2	90	360	Em, S MO
	Stell.	0	10-12	6	1/16-1/8	150		Em
	WC	0	10-23	6	1/16	260+	540	D
Steel (medium-carbon, annealed) SAE 1045	h.s.s.	8	20	6	1/16-1/2	75		Em, S MO
	Co. h.s.s.	8	14	6	1/16-1/2	100		Em, S MO
	WC	0	10-14	6-8	1/32	200-400		D
Steel (high-carbon, annealed)	h.s.s.	8	14	6	1/16-1/2	50		Em, S BO (1-10)
	WC	0	5-10	6	1/16	200+		D
Steel (very hard)	h.s.s.	5	9	6	3/16	25		Em, MO LO, S BO (1-10)
	WC	0	0-10	4-6	1/16	75+		D
Steel (12% Mn, 1.2% C)	Co. h.s.s.	8	14	6-8	1/8	12	240	D
	WC	0	4	6	1/32	40		D
Steel (stainless 18 Cr, 8 Ni)	h.s.s.	8	15	8	1/16	30		Em, S MO
	WC	4	8	6	1/32	150		D
Zinc-base die casting	h.s.s.	8	15-20	6-8	1/16	180		Em, D

* Planer and shaper tools are usually ground with a negative back rake of 3-10 deg. Those tipped with sintered carbide perform more satisfactorily with a negative rake of about 6 deg with somewhat larger side rake.

†Em = Emulsions of soluble oils
S BO = Sulphurized base oils, blended
LO = Lard oil
K = Kerosene
MO LO = Mineral-lard oil
D = Dry
MO = Mineral oils
T = Turpentine
S MO = Sulphurized mineral oils
P + O = Paraffin oil plus 5 per cent oleic acid

‡ If cut dry, have powdered asbestos available to smother possible flames. Use mineral seal oil for MO

for a wide range of cuts and are believed of value for setting up jobs. Tools of different sizes give about the same performance.

The cutting speeds for **parting** (cutoff) and **threading** tools may be one-third and one-quarter, respectively, of the values given in Tables 3 and 4. The former should have light feeds, as the sharp-cornered tools are deeply imbedded in the work.

TABLE 3. CUTTING SPEED IN FEET PER MINUTE FOR A TOOL LIFE OF 90 MIN WHEN CUTTING CAST IRON AT VARIOUS DEPTHS OF CUT AND FEEDS*

Depth of Cut, inches	Feed, inches	Soft Cast Iron	Medium Cast Iron	Hard Cast Iron
3/32	1/64	216	108	63.0
	1/32	160	80.0	46.6
	1/16	110	55.0	32.2
	3/32	88.4	44.2	25.8
	1/8	75.4	37.7	22.0
1/8	1/64	200	100	58.6
	1/32	148	74.0	43.3
	1/16	104	51.8	30.2
	3/32	82.6	41.3	24.1
	1/8	69.6	34.8	20.3
3/16	1/64	183	91.6	53.8
	1/32	135	67.5	39.4
	1/16	94.0	47.0	27.4
	3/32	75.4	37.7	22.0
	1/8	64.3	32.2	18.8
1/4	1/64	171	85.7	50.1
	1/32	126	63.2	36.9
	1/16	87.8	43.9	25.6
	3/32	70.4	35.2	20.6
3/8	1/64	156	77.8	45.4
	1/32	116	57.8	33.8
	1/16	79.7	39.9	23.3

* Taylor's standard 5/8-in.-wide high speed steel round-nose turning tool was used. It had 8-deg back rake, 14-deg side rake, 6-deg relief, and a nose radius of 5/32 in. Cutting was done dry.

NOTE: The above data give

$$V_T = Kf^{-x}d^{-y} = \frac{K}{f^x d^y} = V_{90} = \frac{K}{f^{0.53}\, d^{0.23}}$$

K = 14.7 for the soft cast iron
K = 7.35 for medium cast iron
K = 4.28 for hard cast iron

The life of the tool may be of more importance than the rate of metal removal per tool grind. A tool which is difficult to grind because

TABLE 4. CUTTING SPEED IN FEET PER MINUTE FOR A TOOL LIFE OF 90 MIN WHEN CUTTING STEEL AT VARIOUS DEPTHS OF CUT AND FEEDS*

Depth of Cut, inches	Feed, inches	Soft Steel	Medium Steel	Hard Steel
1/16	1/64	548	274	125
	1/32	358	179	81.6
	1/16	235	117	53.3
3/32	1/64	467	234	106
	1/32	306	153	69.5
	1/16	200	100	45.5
	3/32	156	78.0	35.5
1/8	1/64	417	209	94.8
	1/32	273	136	62.0
	1/16	179	89.3	40.6
	3/32	140	69.8	31.7
3/16	1/64	362	181	82.2
	1/32	236	118	53.8
	1/16	155	77.4	35.2
1/4	1/64	328	164	74.5
	1/32	215	107	48.8
3/8	1/64	286	143	65.0

* Cutting was done dry with the same tool as described in the table for cast iron. For medium and soft steel, the side rake was 22 deg.

NOTE: The above data give

$$V_{90} = \frac{K}{f^{0.61}\,d^{0.36}}$$

K = 15.7 for the soft steel
K = 7.9 for the medium steel
K = 3.6 for the hard steel

of its shape, or difficult to adjust in the machine, or one required to maintain accuracy of size and form should be ground only at long intervals. A finishing tool should turn out many pieces of the same size. A roughing tool may be ground more frequently, as less care is necessary to reset it.

In rough cutting in production, most economical results are obtained when the speed, feed, and depth of cut are correlated so as to cause the tool to fail in a short, definite time. In such cases, the tool forms and sizes are standardized and the grinding is done on machines in quantities.

Cutting-speed tool-life relation: The formula expressing the relation between cutting speed and tool life between grindings for a given tool, material, feed, and depth of cut is $VT^n = C$, in which V is the cutting speed in feet per minute; T is the tool life or duration of cut between grindings in minutes; C is a constant depending on the conditions, and equals the cutting speed for a tool life of 1 min; and n is the slope of the straight line on log-log paper. If three or more turning tests were run on a metal in which all factors were kept constant except the cutting speed, V, a definite value of tool life at failure, T, would be obtained at each cutting speed, as indicated by points p, q, r, and s, on the lowest curve in Fig. 16. These and more points plotted on cartesian coordinates would indicate a parabolic curve. On log-log paper they produce a straight line. The equation of a straight line on cartesian coordinates is $y = mx + b$, but on log-log paper it is $\log y = m \log x + \log b$ (or $\log V = n \log T + \log C$). The slope ($n$) of the line is negative and equals y/x; then $V = T^{-n}C$, or $VT^n = C$. (In Fig. 16 the vertical ordinate scale is 2.67 times the horizontal.) When $T = 1$, then $C = V$ (in feet per minute for a 1-min tool life). Various cutting-speed tool-life lines ($VT^n = C$) are given in Fig. 16 for a constant depth of cut at three different feeds, with and without cutting fluids. Values of n, C, and V_{100} for each line, as well as lines for other values of depth and feed, are given in Table 5. The values of n and C may vary with the tool material, tool shape, size of cut, material cut, and cutting fluid. Definite values from experiments are given in Table 6.

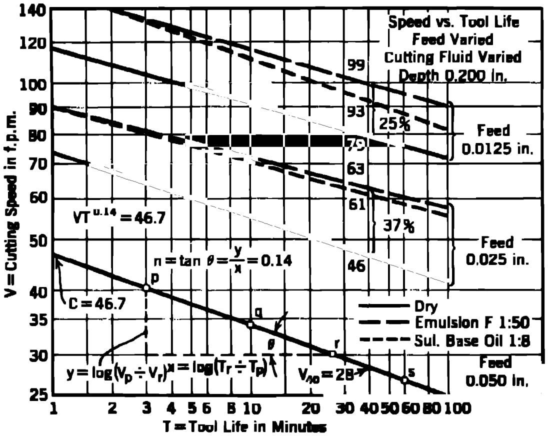


FIG. 16. A Summary of Experimental Data, Showing the Relation between Cutting Speed and Tool Life When Turning SAE 2340 Annealed Steel as the Feed is Varied for a Constant Depth of Cut of 0.200 in. for Each of Three Cutting Fluids.

The high speed steel tools had a form of 8, 22, 6, 6, 6, 15, $\frac{3}{64}$. Values of n and C are given in Table 5. Modified log-log paper; vertical scale = 2.67 times the horizontal.

In these tests tools are considered failed and require regrinding when the flank abrasion is such as to give rise to an appreciable increase in power or to allow the work to be cut oversize. The cupping of steel and cast nonferrous tools may advance and cause chipping of the cutting edge for preliminary failure or the complete breakdown of the cutting edge for final failure, as shown in Fig. 12. For sintered-carbide tools a flank abrasion averaging 0.030 in. below the cutting edge is used to denote failure. Typical failure for such a tool is illustrated in Fig. 13.

TABLE 5. VALUES OF n, C, V_{100}, AND CUBIC INCHES PER TOOL GRIND FOR VARIOUS CUTS IN SAE 2340 STEEL SELECTED FROM FIG. 16

Test No.	Cutting Fluid	Depth of Cut, in.	Feed, ipr	n	Cutting Speed for 1-min Tool Life, C	100-min Tool Life	
						V Cutting Speed	Cubic Inches per Grind
1	Dry	0.050	0.025	0.133	111.0	60.0	90.0
2	Dry	0.0125	0.0125	0.125	313.0	176.0	33.0
3	Dry	0.035	0.0125	0.111	200.0	120.0	63.0
4	Dry	0.100	0.0125	0.147	143.0	72.5	108.8
5	Dry	0.200	0.0125	0.110	117.5	71.0	213.0
6	Dry	0.200	0.025	0.128	74.0	41.0	246.0
7	Dry	0.200	0.050	0.140	46.7	24.5	288.0
8	Em 1:50	0.200	0.0125	0.107	150.0	91.5	274.0
9	Em 1:50	0.200	0.025	0.097	90.0	57.5	345.0
10	SB 1:8	0.200	0.0125	0.132	152.0	82.5	247.5
11	SB 1:8	0.200	0.025	0.103	90.0	55.8	335.0

NOTE: The above data give $V_{90} = \dfrac{K}{f^{0.77}\,d^{0.37}}$

$K = 1.2$ for dry cutting

Influence of size and shape of cut and tool life: For the **constant area of cut** (tests 1 and 4, Table 5), turning SAE 2340 steel, annealed, with high speed steel tools (8, 22, 6, 6, 6, 15, $\frac{3}{64}$), i.e., having 8-deg back rake, 22-deg side rake, 6-deg end relief, 6-deg side relief, 6-deg end-cutting-edge angle, 15-deg side-cutting-edge angle, and $\frac{3}{64}$-in. nose radius, the relation between tool life and cutting speed was $VT^{0.133} = 111$ for the test 1 cut, which was 0.050 in. deep by 0.025 in. feed, and $VT^{0.147} = 143$ for the cut of test 4, 0.100 in. deep by 0.0125 in. feed. The cutting speed for a 1-min tool life is 111 fpm for the heavy feed and 143 fpm, or 29 per cent higher, for the light feed. For a 100-min tool life, the speed, V_{100}, was increased from 60 fpm in the first test to 72.5 fpm in the fourth, or 21 per cent. The metal removed

TABLE 6. EQUATIONS SHOWING THE RELATION BETWEEN CUTTING SPEED AND TOOL LIFE FOR VARIOUS TOOL MATERIALS AND CONDITIONS

Tool			Material Cut	Size of Cut		Cutting Fluid	$VT^n = C$	
No.	Material	Shape		Depth	Feed		n	C
1	H. c. s.	8, 14, 6, 6, 6, 15, 3/64	Yellow brass (0.60 Cu, 0.40 Zn, 0.8 Sn, 0.006 Pb)	0.050	0.0255	D	0.081	242
2	"	"		0.100	0.0127	D	0.096	299
3	"	"	Bronze (0.90 Cu, 0.10 Sn.)	0.050	0.0255	D	0.086	190
4	"	"	"	0.100	0.0127	D	0.111	232
5	H. s. s. (18–4–1)	"	Cast iron (160 B)	0.050	0.0255	D	0.101	172
6		"	" " , nickel (164 B)	"	"	D	0.111	186
7	"	"	" " , Ni-Cr (207 B)	"	"	D	0.088	102
8	"	8, 14, 6, 6, 6, 0, 0	Steel, SAE B1113 (C.D.)	"	0.0127	D	0.08	260
9	"	"	" SAE B1112 "	"	"	D	0.105	225
10	"	"	" SAE B1120 "	"	"	D	0.100	270*
11	"	"	" SAE B1120 + Pb"	"	"	D	0.060	290
12	"	"	" SAE 1035 "	"	"	D	0.110	130
13	"	"	" SAE 1035 + Pb"	"	"	D	0.110	147
14	"	8, 14, 6, 6, 6, 15, 3/64	" SAE 1045 "	0.100	"	D	0.110	192†
15	"	8, 22, 6, 6, 6, 15, 3/64	" SAE 2340 (185 B)	"	0.0125	D	0.147	143‡
16	"	8, 14, 6, 6, 6, 15, 3/64	" SAE 2345 (198 B)	0.050	0.0255	D	0.105	126§
17	"	"	" SAE 3140 (190 B)	0.100	0.0125	D	0.160	178
18	"	"	" SAE 4350 (363 B)	0.0125	0.0127	D	0.080	181
19	"	"	" SAE 4350 (363 B)	"	0.0255	D	0.125	146
20	"	"	" SAE 4350 (363 B)	0.025	"	D	0.125	95
21	"	"	" SAE 4350 (363 B)	0.100	0.0127	D	0.110	78
22	"	"	" SAE 4350 (363 B)	0.100	0.0255	D	0.110	46
23	"	"	" SAE 4140 (230 B)	0.050	0.0127	D	0.180	190
24	"	"	" SAE 4140 (271 B)	"	"	D	0.180	159
25	"	"	" SAE 6140 (240 B)	"	"	D	0.150	197
26	"	8, 22, 6, 6, 6, 15, 3/64	Monel metal (215 B)	0.100	"	D	0.080	170
27	"	"	" " "	0.050	0.0255	D	0.074	127
28	"	"	" " "	0.100	0.0127	Em	0.080	185
29	"	"	" " "	"	"	S MO	0.105	189
30	Stell. 2400	0, 0, 6, 6, 6, 0, 3/32	Steel, SAE 3240, ann.	0.187	0.031	D	0.190	215
31		"	" SAE " "	0.125	"	D	"	240
32	"	"	" SAE " "	0.062	"	D	"	270
33	"	"	" SAE " "	0.031	"	D	"	310
34	Stell. No. 3	"	Cast iron (200 B)	0.062	"	D	0.150	205
35	WC (T64)	6, 12, 5, 5, 10, 45, 0	Steel, SAE 1040, ann.	"	0.025	D.	0.156	800‖
36	"	"	" SAE 1060 "	0.125	"	D	0.167	660
37	"	"	" SAE 1060 "	0.187	"	D	"	615
38	"	"	" SAE 1060 "	0.250	"	D	"	560
39	"	"	" SAE 1060 "	0.062	0.021	D	"	880
40	"	"	" SAE 1060 "	"	0.042	D	0.164	510
41	"	"	" SAE 1060 "	"	0.062	D	0.162	400
42	"	"	" SAE 2340 "	"	0.025	D	0.162	630

* 180 fpm is more normal.

† See Fig. 17 for other structures.

‡ See Table 5 for other cuts and cutting fluids.

§ For values for many cutting fluids, see *Trans. ASME*, May, 1937, p. 343.

‖ See *American Machinist*, May 24 and June 7, 1933.

Example 1:
V = Cutting speed, fpm = 95
T = Tool life, min = 3
n = Slope of the curve = 1/7
Find C in $VT^n = C$
Using slide rule, $95 \times 3^{1/7} = 95 \times 3^{0.1428} = 95 \times 1.17 = 111 = C$

Using logarithms, $95 \times 3^{1/7} = C$

$$\begin{aligned} &\log 95 + 1/7 \log 3 &&= \log C \\ &1.97772 + 1/7 \times 0.47712 &&= \\ &1.97772 + 0.0673 = 2.0440 &&= \log C \end{aligned}$$

$C = 110.7$ (the characteristic 2 determines the decimal-point position)

Example 2: Raising fractional numbers.

$$(0.0125)^{1/7} = ?$$

Using slide rule, $(0.0125)^{0.1428} = \left(\frac{1}{80}\right)^{0.1428} =$

$$\frac{1^{0.1428}}{80^{0.1428}} = \frac{1}{80^{0.1428}} = \frac{1}{1.87} = 0.534 \qquad \textit{Ans.}$$

Using logarithms, $1/7 \log 0.0125 = 1/7\ (-2.09691)$ or

$$1/7\ (68.09691 - 70) = 9.7281 - 10$$

Antilog = 0.5347 *Ans.*

per tool grind at V_{100} is increased from 90 to 108.8 cu in. (*Trans. ASME*, May, 1939, p. 315).

For a given **cross-sectional area of chip**, the greatest cutting speed for a specific life of tool is obtained when the ratio of depth of cut to traverse is large. The cutting speed falls off to a minimum when the ratio of depth to traverse is unity. For values below unity, the speed increases again.

With the **feed constant** at 0.0125 in. (tests 2–5 of Table 5), the cutting speed for a tool life of 100 min varied from 176 to 71 fpm as the depth was multiplied, such as 176 for 1*d*, 120 for 3*d*, 72.5 for 8*d*, and 71 for 16*d*. The metal removed per tool grind at VT_{100} increased from 33 to 213 cu in.

With the **depth constant** at 0.200 in. (Fig. 16, and tests 5–7 in Table 5), C is reduced to 1/2.5, and V_{100} is reduced to 1/3.5 as the feed is quadrupled. The metal removed per tool grind increases only from 213 to 288 cu in. Corresponding values when using an emulsion and sulphurized base oil are given under tests 8–11. The minimum metal per tool grind at V_{100} is removed in the lightest dry cut, test 2, and the maximum in the heaviest wet cut, test 9.

Machinability of Metals

Steels are sent to the shop for machining in a cast, forged, hot-rolled, or cold-finished condition with a fine-, medium-, or coarse-grained structure. They may be fully annealed for a lamellar pearlitic structure, normalized for a fine tempered martensitic (sorbitic) structure, specially annealed for spheroidized structure, or quenched and tempered for tempered martensitic structure. They may have any desired hardness. The machinability rating of a steel is, therefore, a function of many variables, but the tool life does vary, to a considerable extent, inversely with the hardness; i.e., the higher the hardness, the poorer the tool life. Brinell and Knoop hardnesses of a variety of structures and metals are shown in Table 7.

TABLE 7. REPRESENTATIVE VALUES OF BRINELL AND KNOOP HARDNESSES OBTAINED WITH THE TUKON TESTER WITH KNOOP INDENTER DIAMOND NO. 8*

	Brinell	Knoop
Ferrite	90	150
Pearlite, lamellar	250–300	350–450
Pearlite, spheroidized	160–190	. . . .
Cementite	650	1,000–1,100
Sorbite	170–321	450
Austenite, AISI 304 (18 Cr, 8 Ni 0.08 C, max.)	150	. . . .
Martensite	372–600	720
Fused quartz	. . . .	750
Tool steel, oil hardened	(Rc 60.5)	790
Nitrided annealed high speed steel	. . . .	800
Nitrided hardened high speed steel	. . . .	1,100
Chromium-plated high speed steel	. . . .	900
Sintered tungsten carbide	. . . .	1,050
Topaz	. . . .	1,250
Sapphire (synthetic, Al_2O_3)	. . . .	1,525–2,000
Aluminum oxide	. . . .	1,635
Silicon carbide	. . . .	2,000
Boron carbide (molded)	. . . .	2,230
Diamond	. . . .	8,000

* (a) Bureau of Standards Research Paper RP1220 by F. Knoop, C. G. Peters, W. B. Emerson, *Journal of Research*, Bureau of Standards, Vol. 23, July–December, 1939.

(b) "The Knoop Indenter as Applied to Testing Non-metallic Materials from Plastics to Diamonds," by V. E. Lysaght, *ASTM Bulletin* 138, May, 1948.

(c) Hardness ranges for various materials, "Materials and Methods," Engineering File Facts, May, 1948, pp. 105–106.

(d) "The Micro-hardness of Carbides in Tool Steels," by L. P. Tarasov, *Metal Progress*, December 1948, p. 846.

High cutting speeds with long tool life, well-broken-up chips, and smooth, accurately machined surfaces are indications of good machinability. These do not always occur together, so the selection of the steel and its structure must be based on the factor of most importance.

Low-carbon steels, 0.30 per cent carbon and less, give the best machinability ratings when normalized and/or annealed to produce a lamellar pearlitic structure. A quench and temper to produce a fine spheroidite also give good machining properties.

Low-carbon steel machined in the hot-rolled or annealed condition frequently gives short tool life. Large, unbroken areas of free ferrite are detrimental to good machinability. As the cutting edge of the tool passes through the ferrite mass, it is resisted by the soft, rubbery tenacity of the ferrite. The material tears and pulls, producing long chips which slide over a large area of the tool, causing excessive frictional heat. Pearlite, on the other hand, is harder and fractures easily, so that chips of this material are removed with less ductile flow and less distortion, and consequently with the generation of less heat on the tool. For the low-carbon steels it is therefore desirable to decrease the ferrite or modify its structure and increase the proportion of pearlite. This is effective up to the medium-carbon steel range. A coarse as-rolled grain structure of lamellar pearlite and the presence of some constituent which becomes soft at the cutting-edge and chip-tool interface, such as magnesium sulphide or lead, to break up the continuity of the ferrite, greatly improve tool life. Marked banding and heavy ferrite segregation in normalized and annealed steels will reduce tool life and produce a rough, torn surface.

Low-carbon and free-cutting steels for screw-machine work usually are **cold finished** to give accuracy of dimension, freedom from scale, and improved machinability. The cold finishing consists commonly of acid pickling the hot-rolled steel, coating with lime, and cold drawing through a die with a reduction in diameter of 1/32–1/16 in. to desired size. This drawing causes deformation along slip planes within the ferrite grains throughout the bar, disrupting these smooth planes, making the metal harder and more brittle. Low strength and low ductility are desirable factors for machinability.

For example, a piece of standard hot-rolled steel 1 in. in diameter, of 0.18 per cent C and 0.46 per cent Mn, if cold drawn to 15/16 in. diam., will have its properties changed from the values given first to those given second:

Tensile strength, psi	64,300–83,200
Yield strength, psi	48,000–74,000
Elongation, per cent	36–18.5
Reduction of area, per cent	67.8–60.7
Charpy impact, ft-lb	52.7–43.5
Hardness	Rockwell B72 or Brinell 126–B93 or 197

The cold-finished bar shows better machinability in well-broken chips, better surface quality, and longer tool life than the hot-rolled steel. Further increased cold working would raise the tensile and lower the ductility values and improve the machinability, until for higher-carbon steels a maximum value of about 120,000 psi is reached. Beyond this, cutting forces as a result of higher strength become so great that the steel must be annealed. The higher-carbon and alloy steels are generally subject to increases in tensile strength beyond this value by cold finishing, and they must therefore be annealed before being cold drawn or machined in the hot-rolled condition (data furnished by Geo. Witteman, Bethlehem Steel Co.).

The **Bessemer free-cutting steel,** AISI B1112, screw stock, containing 0.16–0.23 per cent sulphur, 0.13 per cent C max., and 0.70–1.00 per cent Mn, is used cold drawn in screw machines for small low-stressed parts. It will not produce high-quality carburized parts, yet it can be cyanide hardened for use where shock is not encountered. Cold-drawn AISI B1113, containing still higher sulphur (0.24–0.33 per cent), machines 20–40 per cent faster but has lower physical properties. **Open-hearth free-cutting steels,** such as AISI C1120, are resulphurized to contain 0.08–0.13 per cent sulphur and are used in substantial quantities. The steel is somewhat stronger than AISI B1112, permits cutting speeds slightly lower, but can be pack hardened satisfactorily. A 1.10–1.40 per cent manganese, 0.16–0.23 per cent sulphur, fast-carburizing steel, such as AISI C1116, is excellent for parts to be carburized, such as forgings, bolts, levers, sprockets, pinions, and rollers. It machines almost as readily as B1112, but must be cut with less rake to break up the chips. The higher-**carbon-manganese steels,** such as 1137 and 1141, 1.35–1.65 per cent Mn and 0.08–0.13 per cent S, machine well and may be heat treated to give high physicals. Values of C for steels 8–13, Table 6, represent current cutting speeds for screw-machine work. **Leaded steels,** containing 0.25 per cent lead, offer 10–40 per cent increased cutting speeds with no deleterious effects on physical properties. They are not popular, because of their health hazard and the persistence of lead in the scrap.

Normalizing also is indicated for the **low-medium-carbon, 0.30–0.40 per cent steels,** the cooling being fast enough to give a pearlitic structure of moderate grain size. A small grain size gives a better surface finish.

The cutting-speed tool-life relationship is shown for a medium-carbon steel, SAE 1045, with different structures in Fig. 17 (*Trans. ASME*, March, 1940, p. 186). The equations of the lines on log-log paper are indicated in the figure. All lines are parallel but are displaced vertically because of the difference in hardness and structure resulting from the different heat treatments. The highest cutting-speed line for the annealed bar, with a pearlitic and ferritic structure, is 80 per cent higher than the lowest line for the quenched bar with a structure of troostite and sorbite. The bar cold finished after annealing has large-grain pearlite with a heavy boundary of ferrite. In the drawn bars, the structure is mostly sorbite (170–321 Brinell) which is hard and tends to give good surface finish but lowers the tool life. The tool life in minutes for a cutting speed of 130 fpm, T_{130}, for the bars from the bottom to top is 0.3, 0.8, 2, 37 and 64. The last value is 2,100 per cent of the first.

For the **high-medium-carbon steels** containing 0.50–0.60 per cent carbon, the annealed structure with lamellar pearlite is best with the pearlitic grains not entirely surrounded with ferrite. The **eutectoid steels** with carbon of 0.85 per cent or more are machined best after the spheroidizing anneal.

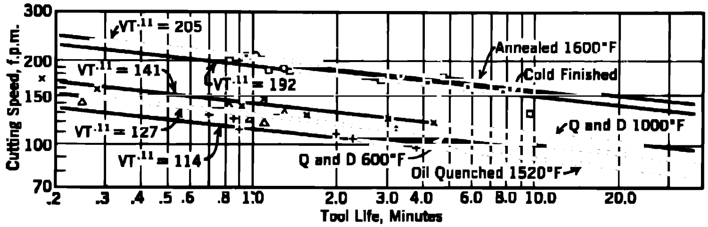


Fig. 17. Tool-Life Cutting-Speed Relations When Turning Annealed, Cold-Finished, and Heat-Treated SAE 1045 Steel, Dry.

Depth of cut 0.100 in., and feed 0.0127 in. High speed steel tools, $\frac{3}{4}$ in. sq., of 8, 22, 6, 6, 6, 15, $\frac{3}{64}$ shape, were used. The machinability ratings of the structures are, from the top down, 60, 55, 42, 36, and 30 per cent, respectively.

In a study of the relation between microstructure and machinability of **alloy gear steels** (*Iron Age*, Sept. 30, 1937, p. 70), Dr. Woldman observed that the oil-hardening steels, such as SAE 6150, 3250, and 4350, which machined best in automatic screw machines had a coarse, spheroidized structure, while the steel which was most difficult to machine had the lamellar pearlitic structure. The SAE 6150 steel, with a fine spheroidized structure, dulled the tools more readily and developed more heat during machining than the coarse spheroidized structure. In broaching, a spheroidized steel gave a ragged, rough, and often a torn surface, while the sorbitic or lamellar pearlitic structure produced a smooth and clean surface and longer tool life. In gear cutting, the spheroidized structure produced a rough surface with burrs on the tooth end, while a lamellar pearlitic or sorbitic structure produced a smooth, clean surface with no burrs adhering. A compromise in structure must be accepted to obtain the most desirable machining by the various processes.

Figure 18*A* shows a series of V–T lines on log-log paper for SAE 4340 steel in a condition of mill annealed and quenched and drawn at several temperatures to produce the hardnesses indicated. An emulsion consisting of a soluble oil reduced with 20 parts of distilled water at a temperature between 100 and 110° F was directed on the tool face at a velocity of 358 fpm to give a volume flow of 3 gal per min.

At a Brinell hardness of 300 the cutting speeds for other SAE steels were as follows: X3045A, 101 fpm; 5145, 103 fpm; 4145, 110 fpm; 4645, 112 fpm; 3145, 118 fpm; and X4345, 120 fpm.

The alloy steels are used where high physical properties are required. The low-carbon, 0.80–0.90 per cent Cr and 0.10–0.15 per cent Va steel,

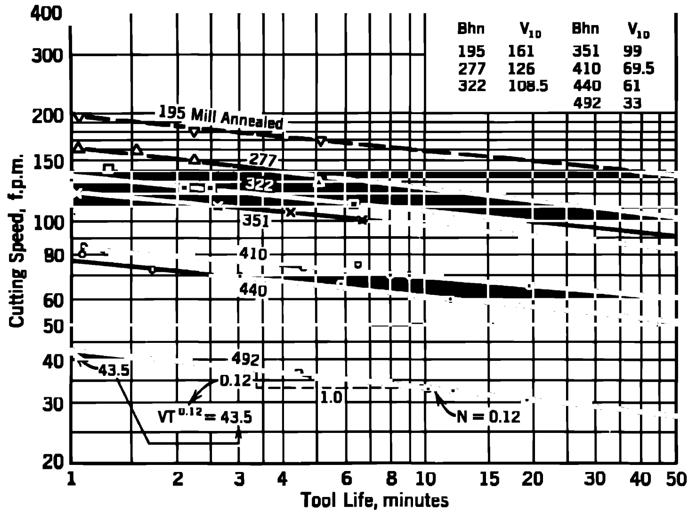
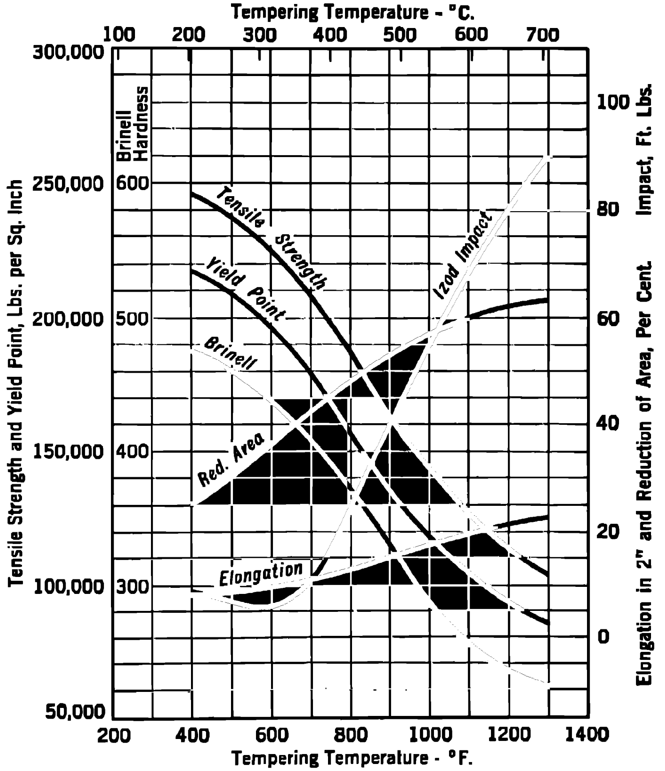


FIG. 18A. Cutting-Speed Tool-Life Lines on Log-Log Paper for 2-in.-diam. Bars of SAE 4340 Steel at Different Brinell Hardnesses When Machined with 18-4-2 High Speed Steel Tools 3/8 in. sq. of a shape of 8, 14, 6, 6, 6, 15, 3/64, with Depth of Cut of 0.050 in. and a Feed of 0.0127 in., Using an Emulsion. (*Trans. ASM*, December, 1943, p. 955).

AISI 6120, machines at about 50 per cent of the speed of Bessemer screwstock but, when carburized and hardened, develops a hard case and exceedingly tough core, the needed combination for shock and wear resistance. The A4340, 6150, 8640, 8740, 9440, etc., steels are the most useful general-purpose alloy steels and, when heat treated, give tensile strengths of 140,000–160,000 psi, yield points of 120,000–135,000 psi, elongations of 15–20 per cent, and reductions of area of 40–50 per cent. They are suitable for highly stressed machine parts, such as pins, constant mesh gears and worms, cams and cam rollers. A nickel-molybdenum steel, SAE 4615, develops a hard case and a core of good ductility with a minimum distortion of the piece.

SAE 3140 steel is used for gears, drive shafts, and other highly stressed parts similar to the 4340 and 6150 mentioned above. Its analysis in per cent is: C 0.34–0.45, Mn 0.60–0.90, Ph 0.04 max., S 0.05 max., Ni 1.00–1.50, Cr 0.45–0.75. Figure 18*B* shows the physical properties of this steel in sizes from ½ in. to 1½ in. diam. or thickness when oil-quenched from 1475 to 1525° F and then tempered at various



Courtesy International Nickel Co.

FIG. 18*B*. The Physical Properties of SAE 3140 Steel When Quenched in Oil and Drawn at Various Temperatures from 400 to 1,400° F.

temperatures indicated on the horizontal scale. This shows how the tensile strength is reduced at high tempering temperatures and how the impact value is increased.

Hard-steel parts showing martensitic or troostitic constituents usually are finished into desired forms in the machine shop by grinding operations. For machining austenitic stainless steels at moderate speed but heavy feeds, tungsten or molybdenum high speed steels are satisfactory. At higher speeds and lighter feeds, cobalt high speed steel or cast-nonferrous-metal tools are better. For production turning at high speeds sintered-carbide tools are best. A full continuous flow of a rich emulsion is desirable, and the cutting should be continuous so as to minimize work hardening, characteristic of these metals. Sulphurized oils are best at low cutting speeds, as in reaming and tapping. Manganese steels (13 per cent Mn) are machined with cobalt high speed steel, cast-metal, or sintered-carbide tools at very low speeds with rather heavy feeds and no interruption of the cutting, as this metal, very soft initially, work-hardens extensively.

Free-turning stainless chromium iron (AISI 416, 13 Cr, 0.10 C) permits the use of tools and 70 per cent of the cutting speeds used on SAE 1112 steel with the same satisfactory finish. The **free-machining 18–8** (18 Cr–8 Ni) stainless steel, AISI 303, containing sulphur or selenium as a free-cutting medium, cuts the machining speed of stainless steels to half that of B1112.

Those metals which work-harden appreciably often are machined in the hot-rolled or annealed condition. A continuous flow of sulphurized oil should be used, and cutting should not be interrupted.

Nonferrous metals also are made free-machining by introducing certain elements. The machinability of **yellow brass,** 1 in Table 6, and high-strength phosphor bronze (88 Cu-4 Sn-4 Zn-4 Pb) is improved greatly by this addition of lead. A free-machining **aluminum alloy,** designated as 11S-T3 by the Aluminum Co. of America, contains 5.5 per cent of copper and 0.5 per cent of lead and bismuth to produce long tool life, a good finish, and well-broken-up chips. It is excellent for screw-machine work. The 17S-T4 alloy is stronger than the 11S but is better for deep-hole drilling.

Gray iron is in a general way lamellar pearlitic steel plus large flakes of graphite. The graphite occupies from 11 to 17 per cent of the volume of the metal. The matrix metal has the tensile strength of steel of similar analysis and microstructure. This may vary from almost pure iron of 40,000 psi to a pearlitic steel of 120,000 psi. By controlling the graphite flakes, tensile strengths between 10,000 psi and 60,000 psi or higher can be produced. ASTM Specification A-48 gives seven classes of gray iron from No. 20 (20,000 psi) to No. 60 (60,000 psi). Gray iron is generally considered easily machinable. The lower-strength irons normally machine fastest and have the best vibration damping capacity. The graphite causes the chips to be well broken. As the brittle chips are broken off, the cutting edge scrapes over the surface, smoothing it and bringing it to size, so that the tools fail by flank abrasion.

White iron composed of pearlite with massive cementite having a Brinell hardness of 600 should be ground or turned with tools of sintered carbide at low speeds and fine feeds. Cast iron with chilled surfaces and inclusions of molding sand usually produces machining difficulties and requires carbide tools operating at heavy feeds.

Iron castings can be stress relieved by holding at 1,000–1,050° F for an hour per inch of heaviest section and cooling slowly, after which the machinability is very good. They also can be quenched and drawn to give a high hardness (550–600 Bhn) for best wear resistance.

A **plain iron,** 3.50 per cent total C, 1.21 Si, and 0.62 Mn, has a tensile strength of 23,900 psi, a Brinell hardness of 165 on the surface to 155 on the interior, and a V_{30} of 121 fpm for a high speed steel tool, 5, Table 6.

A **nickel iron,** 6, Table 6, with 3.43 per cent C, 1.13 Si, 0.53 Mn, and 1.44 Ni, has a Brinell hardness of 163–165, a tensile strength of 28,550 psi, and a V_{30} of 160 fpm on the scale and 123 on the interior.

A **nickel-chromium iron,** 7, Table 6, with 3.52 per cent C, 1.07 Si, 0.56 Mn, 2.26 Ni, and 0.49 Cr, has a Brinell hardness of 207, a tensile strength of 34,000 psi, and a V_{30} of 84 fpm on the scale and 75 on the interior.

Chromium up to 0.30 per cent gives a high-strength hard iron. Molybdenum from 0.20 to 0.50 per cent, as well as chromium and molybdenum together, gives a high-strength hard iron. Nickel-molybdenum additions give the best machining iron, which has high strength and dense structure — good for pump bodies, etc.

Thermosetting **plastics** are readily machined. Molded phenolics (Bakelite) and urea (Plaskon) have high-abrasive and low-heat-dissipating qualities, so care must be exercised not to exceed speeds and cuts which cause overheating and damage both tool and work. Air blasts directed at the cutting edge are effective coolants, minimize friction, and prolong tool life. Liquid coolants are effective but are kept clean with difficulty, and the parts must be cleaned after machining.

When turning, grooving, or undercutting plastics, sharp high speed steel tools may be used at speeds slightly higher than those used on cast iron; i.e., 100–150 fpm. Nitrided and chromium-plated high speed steel or cast nonferrous alloys are more abrasion resistant and will withstand temperatures higher than high speed steel and so operate satisfactorily at 200–300 fpm. For large production, sintered carbides are recommended to be used at speeds of 300–400 fpm. All tools should be ground with a slight rake and a 7–8-deg relief. Diamond tools retain the keenest cutting edge and reduce heat generation.

They may be operated at very high speeds, such as 800–1000 fpm at light finishing cuts, giving accurate sizes with high surface quality. The higher cost is justified for very high production.

Plastics with wood-flour, fabric, and cotton fillers machine best, whereas those with mineral filler are very abrasive and chip readily.

Cutting Forces and Power of Single-Point Tools

A tool is more efficient from a force or power standpoint when the cutting angle is small. The cutting force is reduced nearly one-half when turning cast iron as the rake is increased up to 35 or 40 deg, and when turning steel up to 45–60 deg, after which the rate of reduction in force is less. However, a value of cutting angle is reached where the heat is not carried away from the cutting edge in the same proportion to the rate at which it is generated, or the keen cutting edge is too frail to support the load, and the tool life is shortened.

Cutting forces or power at the cutting tool may be measured in various ways, such as:

1. Dynamometer.
2. Ammeter.
3. Wattmeter.
4. Calorimeter.
5. Thermocouple.

A **dynamometer**, a device which indicates the cutting forces at the tool point, is most reliable, inasmuch as the mechanical efficiencies of the motor and machine are eliminated. Dynamometers have been applied to planers, lathes, milling machines, drill presses, etc. They may hold the work or the tool and measure one or more components of the force. From these forces or energy recorded, the net power at the cutter, hp_c, is determined.

An **ammeter** in the line may be of sufficient value where the voltage is fairly constant as an indication of the power developed by the motor. Ammeters of this type are installed on a number of machine tools such as the Blanchard surface grinder, so that the operator can know at all times the power developed by the motor.

A recording **wattmeter** is more satisfactory, as this automatically compensates for variations in voltage. This device will record the gross horsepower, hp_g, developed by the motor when the machine is under cut, and the tare horsepower, hp_t, developed by the motor when the machine is running idle but not under cut. By subtracting the tare from the gross power, the net power, hp_n, developed by the motor to effect the cutting is developed. This net power times the mechanical efficiency of the machine and motor will give the horsepower at the cutter, hp_c, as discussed below.

A **calorimeter** has also been used to determine the heat balance of all work done in a metal-cutting operation, such as drilling and milling. The work is submerged in a liquid during the cutting, and the total heat developed is absorbed by the liquid, the tool, the chips, and all parts closely associated with the cutting operation, so that the amount of this heat can be computed. It has been found that this heat is practically equivalent to the power developed at the cutter. Cutting temperatures at the tool point have also been determined by means of a tool-work **thermocouple,** a two-tool thermocouple, or two independent tool-work thermocouples of different tool materials working together concurrently under given conditions. The electromotive force developed is recorded on a potentiometer, and the temperature is determined from the emf-temperature calibration curve of the thermocouple.

The forces developed by the cutter of a machine tool and the power requirements of the motor are of importance for several reasons:

1. The selection of the proper size of motor to be employed on the machine tool.
2. The design of the power transmission from the motor to the cutting tool.
3. The design of the feed transmission mechanism, whether hydraulic, pneumatic, or mechanical.
4. The determination of stresses and deflections in the frame and various parts of the machine tool.
5. The purpose of design of jigs, fixtures, and special tools for holding the work during the machining operation.
6. The selection of the proper size of cutting tools and their application.

Straight-Line Cutting

The influence of the thickness (feed) of chip f as represented by the depth of cut per stroke when planing the top of a land of uniform width w is shown in Fig. 19. The area-of-cut A curve is a straight line varying directly as the thickness of chip for the constant width. The total force F at the tool point, as obtained with a dynamometer, forms a curve nearly straight, but slightly concave downward when plotted over A. The total force F divided by the area of the cut A producing that force gives the unit force, F_u, the values of which are shown plotted as a curve concave upward, having the greatest value for the thinnest chip. When the chip is 0.003 in. thick, the unit force is about 365,000 psi. When the thickness of chip is 0.024 in., the unit force is only 190,000 psi. For a further increase in thickness of cut, the unit force would be reduced but little ("A Research in the Elements of Metal Cutting," *Trans. ASME,* Vol. 48, 1926, p. 749).

This shows that thick chips are removed more efficiently, from a force or power point of view, than thin chips. The equation for the total-force F curve is $F = 81{,}300\, wf^{0.77}$, in which w is the width of cut and f the thickness of chip in inches. The formula for unit force, $F_u = 81{,}300/\,f^{0.23}$, shows it to be independent of the width of cut. It will change for different materials and tool shape. In all types of metal-cutting processes, the cutting force remains practically constant as the cutting speed is varied. This statement does not hold for speeds below 10–70 fpm.

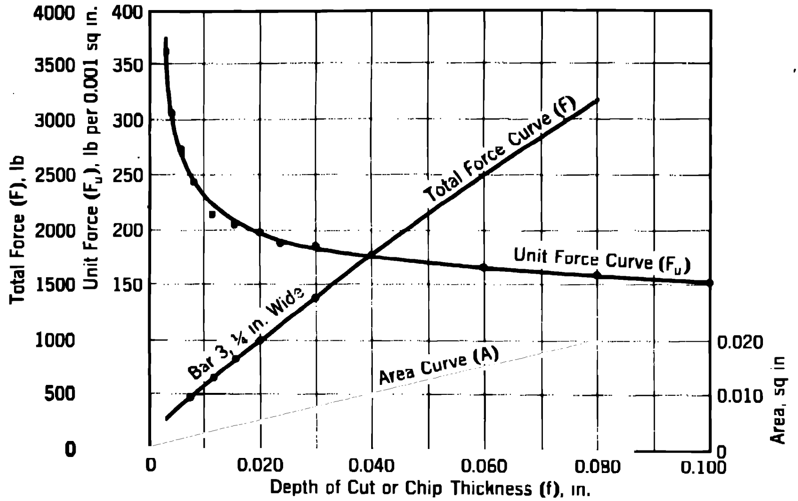


FIG. 19. Cutting Force-Thickness of Chip Curves When Feeding an End-Cutting Planer Tool Vertically Downward at a Feed f in Inches on a Land ¼ in. Wide of Annealed 0.15 Per Cent Carbon Steel.

The tool had a back rake of 30 deg and a relief angle of 4 deg and cut at 20 fpm.

The values of F_u for these conditions for other metals would vary by approximately the following factors: 20,000 psi cast iron annealed, 0.37; the same, as cast, 0.43; rolled brass ½ in. thick, 0.39; SAE 1035 steel,* 0.87; SAE 2320 and 3120 steel,* 0.88; 0.15 per cent carbon steel,* 1.00; SAE 2345 steel,* 1.04; 1.03 per cent carbon steel,* 1.23. These values of F_u would be increased about 1 per cent for each 1-deg reduction in rake angle.

The horsepower developed at the cutter for any metal or condition of speed V, feed f, and width w may be computed in either (or both) of two ways: (a) as computed from the cutting force and (b) as computed from unit horsepower values.

---

* Annealed.

$$(a)\quad hp_c = \frac{\text{Total force, } F \times \text{Cutting speed, } V}{33{,}000} = \frac{FV}{33{,}000}$$

$$= \frac{81{,}300wf^{0.77}V}{33{,}000} \text{ (for this soft 0.15 per cent carbon steel)}$$

If $f = 0.010$ in., $w = \frac{1}{4}$ in., and $V = 20$ fpm,

$$hp_c = \frac{81{,}300 \times 0.25 \times 0.01^{0.77} \times 20}{33{,}000} = \frac{589 \times 20}{33{,}000} = 0.35$$

$$hp_c = hp_c/\text{cu in. per min} \times \text{cu in. per min removed}$$

$$= \text{unit } hp_c \times 12Vwf \text{ (in turning, } w \text{ would correspond to depth } d\text{)}$$

The unit hp_c is 0.88 from Fig. 22 for SAE 1020 forged steel (the nearest type available), for which

$$hp_c = 0.88 \times 12 \times 20 \times 0.25 \times 0.01 = 0.53$$

The SAE 1020 steel from Fig. 22 requires more total power (or 0.88 for unit hp_c) than the 0.15 per cent C steel of Fig. 19. The latter has a unit hp_c value of 0.585. The former has a Brinell hardness of 196 and the latter, 160.

From Fig. 19, the cutting force F, the unit force F_u, the horsepower at the cutter, hp_c, and the net unit power per cubic inch per minute, uhp_c, are as follows for several values of feed, f:

f	F	F_u	hp_c	uhp_c
0.001	100	400,000	0.061	1.0
0.003	274	365,000	0.166	0.92
0.010	575	230,000	0.35	0.585
0.040	1,800	180,000	1.09	0.455

For still thinner chips the power at the cutter will be reduced, but the uhp_c will go higher — even to 15 or 25 for the thin chips of broaching, sawing, and grinding.

A dynamometer may be used on a lathe or planer to determine the tangential cutting force alone, as shown in Fig. 21, or to determine all three components simultaneously, as shown in Fig. 20, for which the results were observed continuously during the cutting until the tool failed. Each component is maximum near the beginning of the cut. As the tool cups, the forces gradually fall off to a minimum at a point when the tool face is grooved the greatest amount. At this time, the new irregular cutting edge formed between the crater and flank breaks off, and preliminary or total failure occurs suddenly and the forces increase rapidly. In turning cast iron, the forces increase slowly till near failure by flank abrasion; then, because of increasing friction between tool flank and work, they increase rapidly.

A formula for the tangential cutting force, F_T, as a function of the feed, f, and depth of cut, d, was determined from the data in Fig. 21. The force values we obtained with a sharp tool after cutting for 30 sec. For a given feed the values of force were determined for each of several depths of cut; then as the depth was kept constant the force was obtained for each of several feeds. These data plotted on log-log paper gave the straight lines indicated. The slope ($\tan \theta = y/x$) of each line represents the exponent of the variable. By substituting a value of F_T for a given f and d, each with its exponent, the constant of the equation is obtained. From these equations, F_T for any combination of depth and feed may then be computed. The exponents of d for the variable-depth lines differ but slightly for the several metallographic structures. The exponents of f in the variable-feed lines vary from 0.97 for the quenched and drawn steel to 0.905 for the annealed steel. The constants show a wide variation (*Trans. ASME*, March, 1940, p. 186).

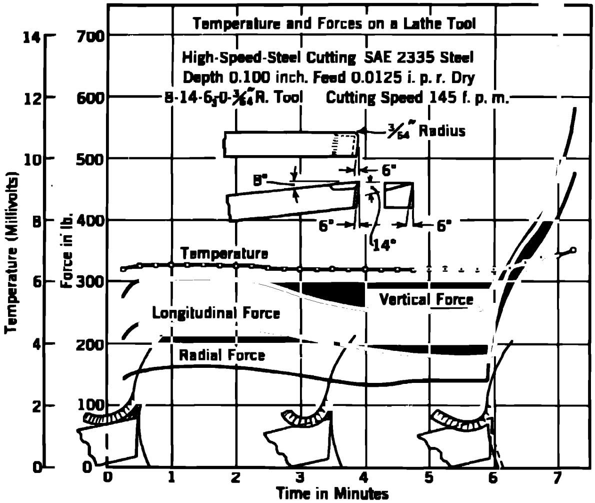


FIG. 20. The Three Components of the Cutting Force on a Turning Tool throughout Its Tool Life as Influenced by the Built-Up Edge and Cupping of the Tool Face When Turning Annealed SAE 2335 Steel.

Equations determined in this manner for each of the three components obtained with a dynamometer, and values of force for a depth of cut of 0.150 in. and a feed of 0.030 in. are given in Table 8 for each of two tool shapes when turning several metals. These forces are independent of speed, and a change in feed here has less effect on F_T than does a proportional change in depth.

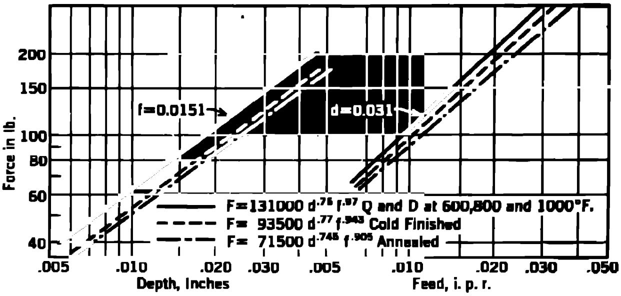


FIG. 21. Tangential Forces on the SAE 1045 Steel of Fig. 17, Using a Tool Shape of 8, 22, 6, 6, 6, 15, 0.01.

For a tool shape of 8, 14, 6, 6, 6, 15, $\frac{3}{64}$, the equation for the solid line becomes $F_T = Cf^{0.86}d^{0.80}$.

(*b*) The horsepower developed at the cutter, hp_c, as determined by dynamometer, would equal the tangential force F_T times the cutting speed V in feet per minute divided by 33,000, thus:

$$hp_c = \frac{F_T V}{33,000}$$

The net power should be divided by the machine efficiency, 20–80 per cent, to get the gross power of the motor, hp_g.

$$\text{The cu in. per min} = 12fdV$$

Thus the horsepower per cubic inch per minute is:

$$uhp_c = hp_c/\text{cu in. per min} = \frac{F_T V}{12 \times 33,000fdV} = \frac{F_T}{396,000fd}$$

Net values, at the cutter, of horsepower per cubic inch of metal cut per minutes, uhp_c, for a variety of metals cut under the conditions indicated in the legend are shown in Fig. 22. These values represent machinability ratings, which would be higher if lighter feeds were used and lower if heavier feeds were used. This chart shows how the machinability rating based on uhp_c varies with the process.

A chart similar to that for milling, Fig. VIII-54, may be obtained with the use of a recording wattmeter. The power developed by the motor is recorded. The machine is first run with the speed and feed drives engaged, and the tare power, hp_t, is recorded. The ma-

TABLE 8. CUTTING-FORCE FORMULAS FOR SINGLE-POINT TOOLS

Formulas developed with a three-component dynamometer when turning with a high speed steel tool. Values of components for a feed of 0.010 in. and depth of cut of 0.100 in. were computed as shown in parentheses:

Tool shape: 8, 14, 6, 6, 6, 15, $^3/_{64}$

(1) 18–8 stainless steel

$F_T = 151{,}000f^{0.85}d^{0.96}$ (329)

$F_L = 23{,}000f^{0.48}d^{1.26}$ (139)

$F_R = 46{,}500fd^{0.69}$ (100)

(2) Hot-rolled SAE 1020 steel

$F_T = 133{,}000f^{0.85}d^{0.98}$ (281)

$F_L = 113{,}000f^{0.8}d^{1.46}$ (101)

$F_R = 3{,}565f^{0.67}d^{0.47}$ (553)

(3) Yellow brass

$F_T = 83{,}400f^{0.81}d^{0.96}$ (223)

$F_L = 95{,}100f^{0.91}d^{1.43}$ (53.4)

$F_R = 9{,}860f^{0.97}d^{0.38}$ (46)

(4) Leaded brass

$F_T = 33{,}550f^{0.83}d^{0.83}$ (108)

(5) Cast iron

(a) 126 Bhn, $F_T = 29{,}400f^{0.78}d^{0.89}$ (105)
$F_L = 8{,}000f^{0.5}d^{1.3}$ (40)

(b) 181 Bhn, $F_T = 54{,}500f^{0.78}d^{0.89}$ (195)
$F_L = 12{,}000f^{0.5}d^{1.3}$ (60)

(c) 241 Bhn, $F_T = 64{,}000f^{0.78}d^{0.89}$ (228)
$F_L = 13{,}500f^{0.5}d^{1.3}$ (77.5)

Tool shape: 8, 14, 6, 6, 6, 0, $^3/_{64}$	**8, 22, 6, 6, 6, 0, $^3/_{64}$**
(6) Low-carbon steel, annealed, 100 Bhn, 80 fpm	
$F_T = 133{,}000f^{0.83}d$ (290)	$F_T = 102{,}500f^{0.8}d$ (257)
$F_L = 33{,}700f^{0.48}d^{1.45}$ (131)	$F_L = 12{,}600f^{0.42}d^{1.35}$ (81)
$F_R = 923f^{0.56}$ (70)	$F_R = 704f^{0.46}d^{0.13}$ (62.5)
(7) SAE 3135 steel, annealed, 207 Bhn, 50 fpm	
$F_T = 259{,}000f^{0.98}d$ (285)	$F_T = 174{,}000f^{0.9}d$ (275)
$F_L = 950d^{1.08}$ (166)	$F_L = 950d^{1.08}$ (79)
$F_R = 7{,}300f^{0.74}d^{0.28}$ (127)	$F_R = 25{,}700f^{0.84}d^{0.58}$ (147)

chine is then operated under cut, and the gross power, hp_g, is recorded. The net power $hp_n = hp_g - hp_t$. Representative values from a test of a $^3/_8$-in.-sq high speed steel tool, ground to a shape of 8, 22, 6, 6, 6, 15, $^3/_{64}$, when turning SAE 3140 steel, normalized and annealed to give 220 Bhn at $f = 0.010$ in., $d = 0.050$ in., $V = 150$ fpm, are as follows: The tool life to complete breakdown was 18.02 min. The cubic inches of metal removed per minute equals $f \times d \times 12V = 0.9$. The gross power was 1.70 kw, the tare was 1.10 kw, giving a net power of 0.60 kw, which divided by 0.746 gives 0.81 hp_n. This, divided by the cubic inches removed per minute, gives the unit net horsepower of 0.9, which agrees fairly well with the values for the similar steels SAE 2320 and SAE 2345 in Fig. 22. $hp_n = \dfrac{F_T \times V}{33{,}000}$. From this, F_T is found to be 179 lb.

A sintered-carbide (grade 78B for steel) tipped tool of a shape 0, 8, 7, 7, 8, 0, $\frac{1}{32}$, turning the above steel at 0.03 feed, 0.050 depth, and

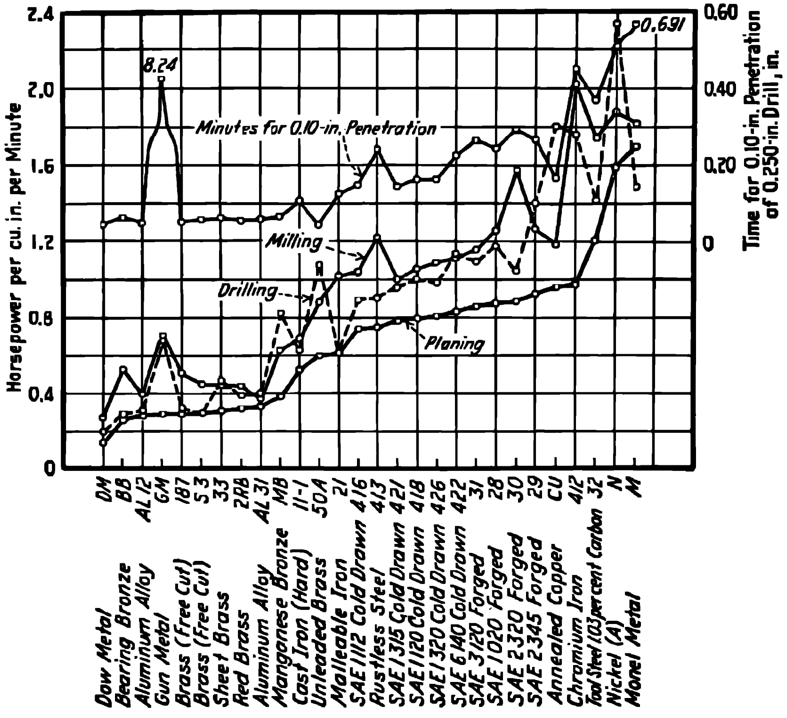


FIG. 22. Net Values of Horsepower at Cutter, per Cubic Inch of Metal Cut per Minute, uhp_c, for a Variety of Metals as Determined for Drilling, Milling, and Planing.

The drill used was $\frac{3}{4}$ in. diam., had a 30-deg helix, and was operated at 153 rpm and 0.012 ipr feed. The planing tool was of the end-cutting type $\frac{1}{2}$ in. wide, having 15-deg back rake, no side rake, and operated at a speed of 20 fpm when taking a depth of cut per stroke of 0.010 in. The milling cutter was of the end-cutting type 0.25 in. wide, 3.5 in. diam., having 15-deg back rake, no side rake when taking a depth of cut of 0.125 in., and a feed of 0.010 in. per tooth. The penetrator drill indicating machinability was $\frac{1}{4}$ in. diam., had a helix of 24 deg, and operated under a feed load of 94 lb at 500 rpm.

300 fpm, gave 4.5 cu in. per min, 4.12 kw_g and 1.2 kw_l or 3.91 hp_n. The uhp_n was 0.87, and F_T was 430 lb.

The horsepower at the cutter, hp_c, is sometimes found from hp_n by determining the power delivered to the spindle for each hp_g by running Prony brake tests on the spindle. This gives average values of $hp_c = 0.80$ hp_m.

NOMOGRAPH FOR TOOL LIFE AND POWER

A nomograph, Fig. 23, represents a simplified summary of the effects of the various machining factors of the tool, material, speed, depth of cut, and feed, on the life and power of single-point tools. Assuming values for five of six variables, the sixth may be obtained from the graph as illustrated in Fig. 23. A sample calculation is given for tool life at the left of center, and one for power at the right, as illustrated. This is accomplished by connecting selected values on lines from points across product lines *A*, *B*, and *C*. Various pairs of speed and feed values giving constant tool life may be found from the chart at the left.

The power at the cutter, hp_c, in the chart at the right is based on relatively dull tools, which require about 35 per cent more power than freshly ground tools. The chart shows how the factors of a given machining operation for the steel and single-point tool can be adjusted with the tool life, so that the motor is loaded to rated capacity.

A machinability rating for each of a number of metals is given in Table 9 to show in a general way the speeds appropriate for the initial setting up of jobs for commercial practice. These speeds may be adjusted to suit specific conditions as experience warrants.

Surface Quality

To secure the best surface quality on a metal of a given structure, the built-up edge should be small or entirely eliminated, so that when cutting:

1. The chip thickness should be small either through small depth or through small feed.
2. The true rake angle of the tool should be large.
3. The nose radius should be large, the end-cutting-edge angle should be small, or a flat should be provided.
4. The cutting speed should be high.
5. Cutting fluids should be used, at low cutting speeds particularly.
6. The side-cutting-edge angle should be large for better chip removal.
7. Conditions should be selected for maximum metal removal per tool grind, and then adjustments made for best finish.
8. High hardness and strength, low ductility, and low work hardening of the material cut favor good surface quality.

Figure 5 shows that at relatively low speeds the cutting edge of the tool does not produce the machined surface. The cutting edge is removed from the surface by 0.003 in. for the conditions shown. As

TABLE 9. MACHINABILITY RATINGS OF AISI STEELS AND VARIOUS FERROUS AND NONFERROUS METALS TO THE NEAREST 5 PER CENT, BASED ON 100 PER CENT RATING FOR BESSEMER SCREWSTOCK AISI B1112, COLD DRAWN WHEN TURNED WITH A SUITABLE CUTTING FLUID AT 180 fpm UNDER NORMAL SCREW-MACHINE CONDITIONS*

AISI No.	Machinability Rating, %	Brinell Hardness
C1008	50	126–163
C1010	50	131–170
C1015	50	131–170
C1016	70	137–174
C1020	65	137–174
C1022	70	150–192
C1030	65	170–212
C1035	65	174–217
C1040*	60	179–229
C1045*	60	179–229
C1050*	50	179–229
C1070*	45	183–241
C1109	85	137–166
B1111	95	179–229
B1112	100	179–229
B1113	135	179–229
C1115	85	143–179
C1117	85	143–179
C1118	80	143–179
C1120	80	143–179
C1132	75	187–229
C1137	70	187–229
C1141	65	183–241
1320	50	170–229
1330†	50	179–235
1335†	50	187–241
1340†	45	187–241
2317	55	174–217
2330†	50	179–229
2340†	45	187–241
2515†	30	179–229
3120	60	163–207
3130†	55	179–217
3140†	55	187–229
3145†	50	187–235
E3310†	40	170–229
4023	70	156–207
4027†	70	166–212
4032†	65	170–229
4037†	65	179–229
4042†	60	183–235
4047†	55	183–235
4130†	65	187–229
4137†	60	187–229
4145†	55	187–229
4150†	50	187–235
4320	55	179–228
4340	45	187–241
4615	65	174–217
4640†	55	187–235
4815	50	187–229
5120	65	170–212
5140†	60	174–229
5150†	55	179–235
E52101‡	30	183–229
6120	50	179–217

AISI No.	Machinability Rating, %	Brinell Hardness
6145†	50	179–235
6152‡	45	183–241
NE8620 or 8720	60	170–217
NE8630† or 8730†	65	179–229
NE8640† or 8740†	60	179–229
NE8645† or 8745†	55	183–235
NE8650† or 8750†	50	183–241
9260†	45	187–225
E9315	40	179–229
NE9440†	60	179–229

Type	Machinability Rating, %	Brinell Hardness
Aluminum 2-S	300–1,500	
Aluminum 11-S	500–2,000	
Aluminum 17-S	300–1,500	
Brass — leaded	300–600	
Brass — red	200	
Brass — yellow	200	
Bronze, lead bearing	200–500	
Bronze, manganese	150	
Copper — cast	70	
Copper — rolled	60	
Dowmetal	500–2,000	
Everdur	120	
Gun metal	60	
Inconel	45	
Iron — cast (hard)	50	220–240
Iron — cast (medium)	65	193–220
Iron — cast (soft)	80	160–193
Iron — ingot	50	101–131
Iron — malleable (standard)	120	110–145
Iron — malleable (pearlitic)	90	180–200
Iron — malleable (pearlitic)	80	200–240
Iron — stainless (12% Cr.F.M.)	70	163–207
Iron — wrought	50	101–131
Magnesium alloys	500–2,000	
Monel metal — cast	35	
Monel Metal — " K "	50	
Monel metal — rolled	45	
Nickel	20	
Ni-Resist†	30	
Steel — cast (0.35 carbon)	70	170–212
Steel — high speed ‡	30	
Steel — manganese (oil hardening)‡	30	
Steel — stainless (18–8 austenitic)†	25	150–160
Steel — stainless (18–8 F.M.)	45	179–212
Steel — tool (high-carbon, high-chromium)‡	25	
Steel — tool (low-tungsten, chromium, and carbon)‡	30	200–218
Zinc	200	

* Data prepared by E. M. Slaughter and O. W. Boston, Jan. 27, 1947.

†, ‡ The terms " annealed " (†) and " spheroidized anneal " (‡) refer specifically to the commercial practice in steel mills, before cold drawing or cold rolling, in the production of the steels specifically mentioned.

the speed is increased, the built-up edge is reduced in size, and a speed is reached, called the optimum speed, at which the built-up edge recedes from the cutting edge and the cutting edge actually produces the machined surface. The surface is not changed further for the higher speeds.

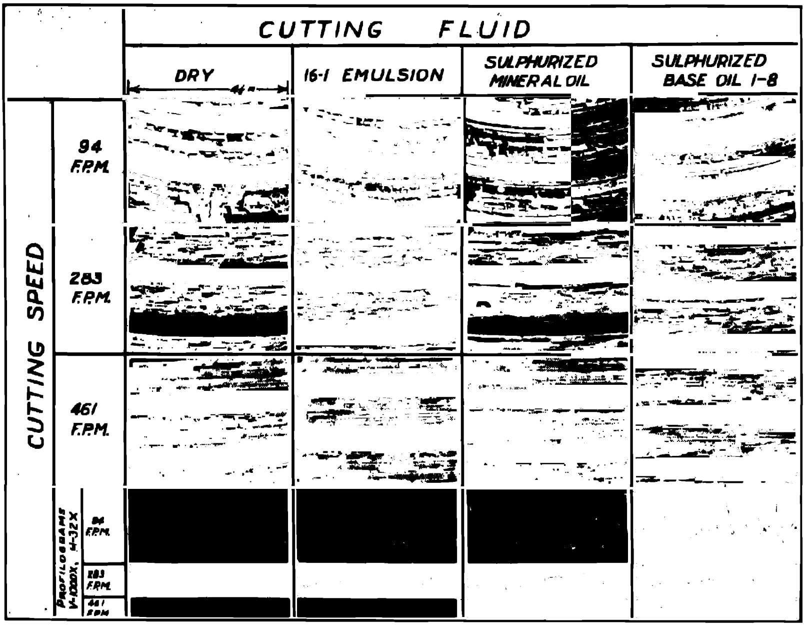


FIG. 24. Surface Quality, at Three Cutting Speeds, Represented by Photographs and Profilograms When Facing an SAE 3140 Steel Normalized and Annealed.

A tungsten-tantalum-carbide tool was used, having a shape of 6, 6, 6, 6, 6, 0, 1/16, operating at a feed of 0.0625 ipr, and a depth of cut of 0.0035 in., for each of four cutting fluids. Original profilograms taken at $V = 1000\times$ and $H = 32\times$, and photographs at 40×. Above cut is one-fifth original size to give 8× for the photographs.

Figure 24 shows for each of three speeds — low, medium, and high — that the surface finish is poor when cutting dry and with three cutting fluids at the lowest speed of 94 fpm. The surface is greatly improved when the speed is increased to 283 fpm. It is best, and the cutting edge actually is producing the machined surface, when a cutting speed of 461 fpm is reached. Profilograms are given for each of these surfaces taken along a path at the bottom of the cut, in the direction of the cut, as shown on the photograph under the emulsion for the highest speed. The scale of the profilogram is shown with the record for the lowest speed of the emulsion. This shows that the surface quality is markedly improved with an increase in cutting speed.

There appears to be little improvement in the surface quality for any constant cutting speed as the **cutting fluid** is varied. This holds true particularly at the highest speeds.

The optimum speed, that is, the minimum speed to produce the best surface, is almost inversely proportional to the **hardness of the steel.** For different structures of the SAE 3140 steel, the optimum speeds are as follows:

461 fpm for the steel normalized and annealed, 202 Bhn.

248+ fpm for the steel normalized at 1,600° F, 277 Bhn.

280 fpm for the steel oil-quenched at 1,500° F and drawn at 1,200° F, 255 Bhn.

95 fpm for the steel quenched and drawn at 600° F, 460 Bhn.

QUESTIONS

1. What is meant by a single-point tool?

2. What is meant by intermittent cutting? Give two or three illustrations.

3. Name several materials of which cutting tools are made and briefly describe each.

4. What is meant by tool quality, and what are the important factors of tool quality?

5. What is meant by cutting angle?

6. Explain the difference between a solid or shank type, tipped, and bit tool.

7. What is meant by the machinability of a cutting tool? State three factors which influence its efficiency.

8. What is meant by the machinability of a metal being cut?

9. Explain the formation of ductile chips.

10. Explain the formation of brittle chips.

11. Explain how the tool profile affects the power requirement as well as the tool life when the depth of cut, feed, and speed are constant.

12. Assuming the length of a cast-iron column to be 24 in., its original diameter 2½ in., and the finished diameter 2¼ in.:

(*a*) Figure the time to take the roughing cut, the finishing cut, and the total cutting time if two cuts are made. The feed for the roughing cut is 0.015 in. and for the finishing cut is 0.010 in. The cutting speed is 75 fpm.

(*b*) What depth of cut would you use for the roughing and finishing cuts?

(*c*) Sketch a properly ground Stellite tool for the above job and indicate all angles and the important dimensions with values.

13. A 0.30 per cent carbon cold-finished-steel shaft, the original diameter of which is 6 in., is being turned to a diameter of 5¾ in., in an engine lathe. The cutting speed in feet per minute for the high speed steel tool is 70, and the feed is 0.020 ipr.

(*a*) Find the revolutions per minute of the lathe spindle.

(*b*) Find the depth of cut in inches.

(*c*) Find the length of bar turned to the new diameter in 1 min.

(*d*) Find the number of minutes required to turn the new diameter a total length of 10 in.

(*e*) Draw a sketch showing the tool shape to be used, and indicate the value of all dimensions and angles.

(*f*) Make a sketch of the shape of the cut being taken, and indicate the depth of cut and feed.

14. A high-tungsten cobalt-steel cutting tool $\frac{5}{8}$ in. wide by 1 in. deep having a shape 8, 14, 6, 6, 6, 30, $\frac{1}{8}$, is cutting SAE 2320 steel, i.e., 3.5 per cent nickel and 0.20 per cent carbon, which is heat treated so as to have 100,000 psi tensile strength. The cutting is done dry, the tool being placed at right angles to the work with the nose at dead center. The depth of cut is $\frac{3}{16}$ in., and the feed is $\frac{1}{16}$ in. It was observed that, when cutting at a speed of 162 fpm, the tool had a life of 1 hr.

(*a*) Make a sketch of the tool, showing its shape and the various angles.

(*b*) From the above information, compute and tabulate the tool life for speeds of 40, 90, 120, and 180 fpm, respectively, plot these data on cartesian coordinate paper at a small convenient scale, and show a smooth curve through all points, using speed as ordinates and tool life as abscissas. Use $n = 0.1428$.

(*c*) Plot the data computed in (*b*) on log-log paper and check the exponent of T.

15. In turning SAE 3150 steel, annealed, the force in pounds on the cutting tool in the direction of cut may be expressed by

$$F_T = Cd^{0.95}f^{0.79}$$

When cutting with a light mineral oil containing 10 per cent lard oil, and taking a cut 0.200 in. deep with a feed of 0.036 in., the pressure was found to be 2,020 lb. The tool had the following shape: 8, 14, 6, 6, 6, 0, $\frac{1}{32}$.

(*a*) For the conditions given above, find the constant C.

(*b*) Find F_T in pounds if the cut is changed from that given above to a depth of 0.05 in. and a feed of 0.036 in.

(*c*) Find F_T if the cut is 0.200 in. in depth and the feed is 0.020 in.

(*d*) Find F_T if the cut is changed to $\frac{1}{16}$ in. depth but 0.020 in. feed.

(*e*) Find F_T if the cut is changed to 0.030 in. and a feed of 0.0089 in.

(*f*) Plot the forces computed in (*b*) to (*e*), incl., on rectangular coordinates over the area of cut in square inches.

(*g*) Find the constant C for dry cutting, if the cutting force is 2,183 lb when $d = 0.2$ in. and $f = 0.036$ in.

(*h*) What is the force saving in per cent produced by the use of the oil over dry cutting?

16. When turning SAE X1112 steel with high speed steel tools of constant shape, the following formulas describe their performance:

(*a*) $VT^{0.13} = 370$ when $d = 0.050$ in. and $f = 0.012$ in.

(*b*) $V_{10} = K_1 f^{-0.6} d^{-0.2}$ where $K_1 = 10.62$.

(*c*) $V_{60} = K_2 f^{-0.6} d^{-0.2}$ where $K_2 = 8.45$.

Find the cutting speed for a tool life of 6 hr when cutting the above steel with the same tools, using a depth of cut of 0.100 in. and a feed of 0.006 ipr.

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CHAPTER VIII

MILLING

DEFINITION

Milling is a cutting process in which rotary cutters, provided with one or more teeth, are used. It differs in most respects from drilling and boring in that flat or formed surfaces usually are produced. The cut of each tooth is not continuous but intermittent on the feeding side of the cutter. In general, the cutter rotates on an axis for **cutting speed** while the work carried on the table is **fed** into the cutter. A rigid definition of milling is not possible because of the many varied applications.

Milling machines, as well as cutters, differ widely in their construction and use. Some machines are designed with every possible convenience and provided with various attachments for toolroom or jobshop work, in which the nature of the work changes often and a wide variety of sizes and shapes of cutters is required. Other milling machines are designed principally for production work, for which purpose they are provided with fixtures specially constructed to hold the particular part to be machined, and with standard or special cutters best adapted to the work. For repetition work, milling has almost entirely superseded shaping and planing. The use of easily made form cutters readily permits complicated contours or curved surfaces to be produced in multiple.

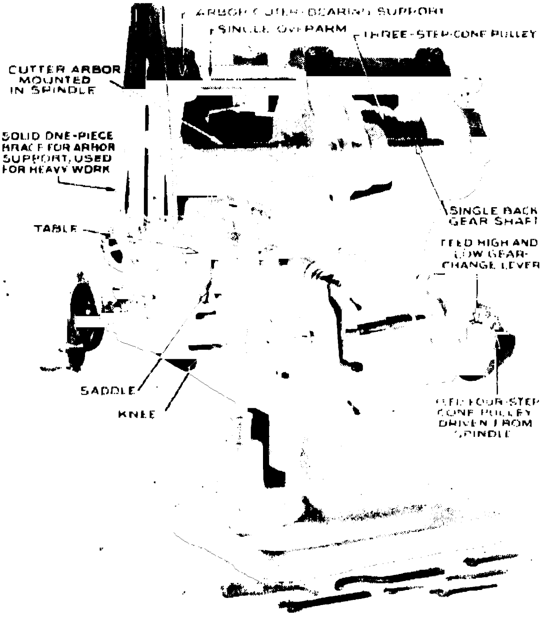
CLASSIFICATION OF MILLING MACHINES

Existing types and sizes of milling machines are so numerous, and their designs merge into one another to such an extent, that it is difficult to classify them definitely. A classification based on general appearance or design and use is as follows:

1. Column and knee, or fixed-bed type.
2. Plain or universal.
3. Step-cone-pulley or constant-speed-pulley drive.
4. Bench or floor mounting.
5. Horizontal or vertical spindle.
6. Hand, mechanical, or hydraulic feed.
7. Job shop or manufacturing.
8. Horizontal boring, drilling, and milling.

9. Reciprocating (planer type), or rotary tables (rotary, offset, or drum type).
10. Thread milling and planetary milling.
11. Diesinking.

Column-and-knee-type milling machines, Fig. 1, are used for general work, job shop, or low production. The table on which the work is held is gibbed to a saddle in turn gibbed at right angles to a knee, which is gibbed on its side to the face of the column, so that it can be moved to and clamped in any desired vertical position for work.


ARBOR CUTTER-BEARING SUPPORT
SINGLE OVERARM
THREE-STEP-CONE PULLEY
CUTTER ARBOR MOUNTED IN SPINDLE
SOLID ONE-PIECE BRACE FOR ARBOR SUPPORT, USED FOR HEAVY WORK
TABLE
SINGLE BACK GEAR SHAFT
FEED HIGH AND LOW GEAR-CHANGE LEVER
SADDLE
KNEE
FEED FOUR-STEP CONE PULLEY DRIVEN FROM SPINDLE

Courtesy R. K. LeBlond Machine Tool Co.

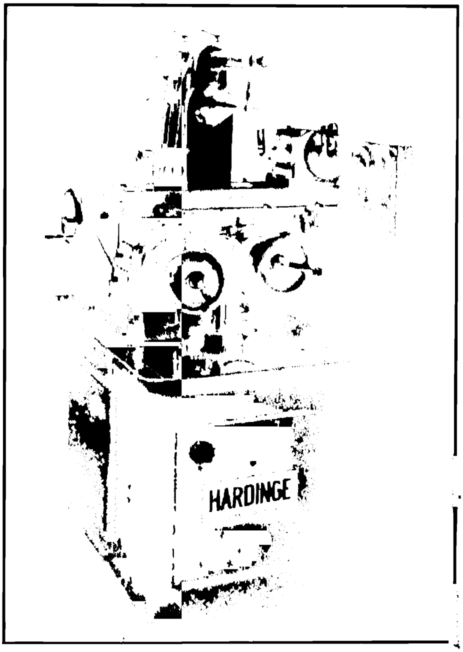
FIG. 1. A LeBlond No. 1B Plain Milling Machine of the Knee Type, 1919 Model, Equipped with Arbor and Plain Milling Vise.

This is a three-step-cone-pulley-drive machine with single back gears of 6.41 to 1 ratio. A two-speed countershaft provides twelve spindle speeds ranging from 12 to 361 rpm. The feed mechanism is driven from the spindle by belt on a four-step-cone pulley with high- and low-gear change providing eight feeds ranging from 0.004 to 0.100 ipr of the spindle.

The horizontal knee-type machines are made **plain** or **universal.** The plain type, Fig. 1, permits three motions of the table: longitudinal, transverse, and vertical; while the universal type, shown in Figs. 2 and 5, permits the fourth motion, which is a swiveling of the table. The spindles have only a rotating motion.

Step-cone-pulley and back-gear drive are applied to the plain knee-type miller in Fig. 1, and the **bench-type** universal in Fig. 2. **Direct-motor drive,** with the motor mounted in the base of the column, is applied to the plain miller in Fig. 3, and to the universal in Fig. 5.

The knee-type miller also is made with a **horizontal,** Fig. 1, or **vertical spindle,** Fig. 7. The fixed head of the vertical-type machine



Courtesy Hardinge Brothers, Inc.

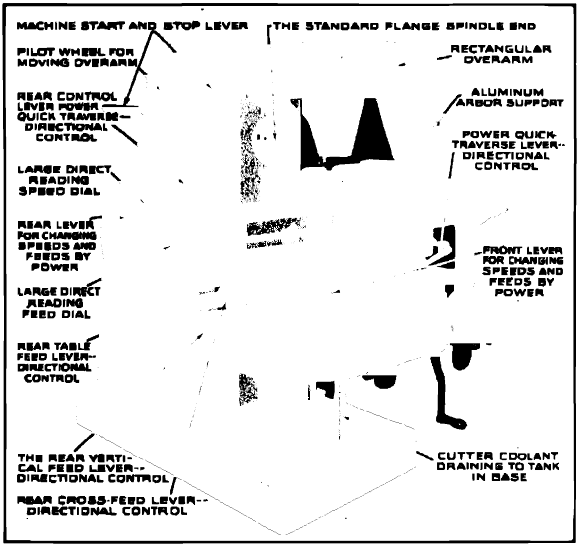
FIG. 2. The Hardinge Type UM Universal High-Speed, Precision, Horizontal Milling Machine for Toolroom and Laboratory Work.

It has eight speeds from 110 to 1,875 rpm with V-belt drive to the spindle from a two-speed, reversing motor. It has thirty-two feeds, ranging from $^1/_8$ in. to 13 ipm. The spindle has a 1-in. collet capacity and takes a 1-in.-diam arbor. The table travel is 14 in. longitudinal (only $11^1/_2$ with power feed), $5^1/_2$ in. tranverse, and $13^1/_4$ in. vertical.

may contain a vertically fixed spindle, or a spindle with vertical hand or power feed. Some spindles are mounted in heads which slide with hand or power feed vertically on the face of the column, Fig. 7.

They are adapted to use a face or end mill cutter for facing, die-sinking, etc., or for drilling, boring, T slotting, and so forth. They are often provided with a rotary table operated by hand or power for circular milling or profiling.

By **centralized control,** the operator can control all operations of the machine while standing in his working position. In many instances, **dual control** is furnished which makes it possible for the operator completely to control the machine from the front or rear. The **lubrication** of all machine parts is effected by force feed and splash. Large micrometer **setting dials** on the various feed screws, **power feed**, and power **rapid traverse** in all directions usually are provided.


MACHINE START AND STOP LEVER
THE STANDARD FLANGE SPINDLE END
PILOT WHEEL FOR MOVING OVERARM
RECTANGULAR OVERARM
REAR CONTROL LEVER POWER QUICK TRAVERSE—DIRECTIONAL CONTROL
ALUMINUM ARBOR SUPPORT
POWER QUICK-TRAVERSE LEVER—DIRECTIONAL CONTROL
LARGE DIRECT READING SPEED DIAL
REAR LEVER FOR CHANGING SPEEDS AND FEEDS BY POWER
FRONT LEVER FOR CHANGING SPEEDS AND FEEDS BY POWER
LARGE DIRECT READING FEED DIAL
REAR TABLE FEED LEVER--DIRECTIONAL CONTROL
THE REAR VERTICAL FEED LEVER--DIRECTIONAL CONTROL
CUTTER COOLANT DRAINING TO TANK IN BASE
REAR CROSS-FEED LEVER--DIRECTIONAL CONTROL

Courtesy Cincinnati Milling Machine Co.

FIG. 3. The Cincinnati No. 2 Plain Knee-Type Milling Machine.

On this machine, any speed or feed may be selected by power from the front or rear of the machine by shifting the speed-feed lever to the right for feeds, or to the left for speeds, until the desired speed or feed is read on the direct-reading dial. Sixteen speeds ranging from 20 to 500 rpm, and sixteen feeds ranging from ½ in. to 20 in. per min are provided as standard. Complete speed-feed and power-rapid-traverse controls are provided on the front and rear of the machine. Power rapid traverse in all directions is provided with the spindle stopped or running. The rectangular overarm carries self-oiling aluminum arbor supports. The 5-hp driving motor is inclosed in the base of the machine. A one-shot lubricating system is provided for saddle and table.

Hand millers are usually small milling machines of the column and knee type, the feeding movements of the table of which are hand controlled. They are sensitive, as the cutting pressure can be felt, and they are used principally in the manufacture of small lots of light work.

The **fixed-bed** or **manufacturing-type** milling machines, as illustrated in Fig. 8, offer a rigid construction and simple operation for production of relatively small parts in quantities. These machines may be built in the **simplex** or **duplex** pattern. The simplex millers, Fig. 8, have but one column on which the vertically adjustable spindle housing is mounted; the duplex machines have two columns on which opposed spindles may be mounted. The two columns may be joined by a bridge on which vertical spindles are mounted, so that milling two sides and the top of the work may be accomplished at one pass.

The **manufacturing type** of machine, Figs. 6 and 8, is often called **semiautomatic,** inasmuch as, with proper fixtures, the work may be clamped and the machine started through a definite automatic cycle, such as rapid advance of work to the cutter, cutting feed, rapid return to the starting position, and stop. Such operations are indicated in Fig. 9. These machines are usually of the fixed-bed type.

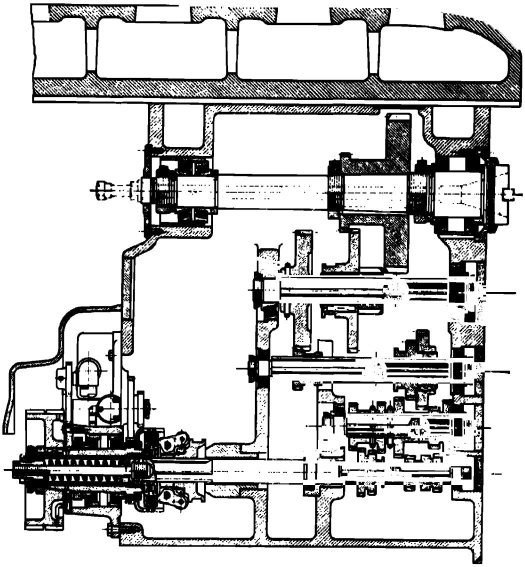


FIG. 4. A Sectional View of the Spindle Driving Gears of the No. 2 Cincinnati Plain Milling Machine.

Power is supplied from the motor in the base to the sprocket wheel at the lower left. Only four gears are in contact for any given spindle speed. All driving gears are mounted on shafts supported on anti-friction bearings and run in a bath of oil supplied by a gear pump located over the driving sprocket wheel.

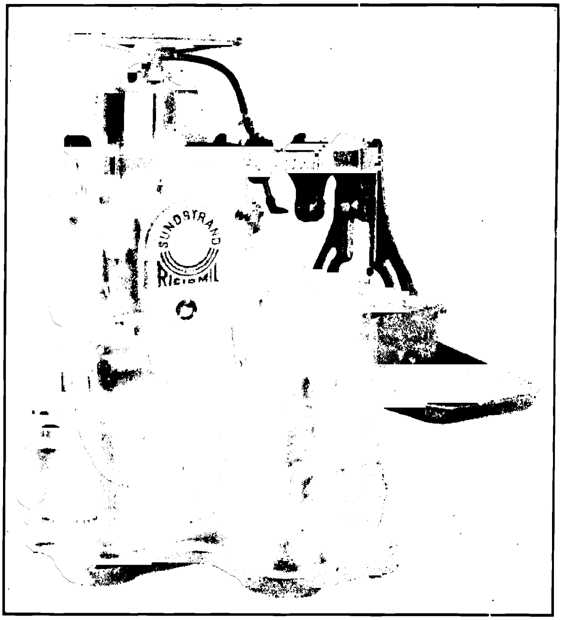
Some machines of this type, Fig. 8, are provided with a means of feeding the work into the cutter hydraulically. This type of feed makes it possible to control the rate of feed accurately and to vary the feed during the cut, Fig. 9.

Horizontal boring, drilling, and milling machines, such as that illustrated in Fig. 10, are provided with a horizontal spindle which is adjustable both longitudinally and vertically. The table of the machine on which the work is mounted is adjustable longitudinally and transversely and may be provided with a rotary table. An almost unlimited variety of operations may be performed on such a machine. Figure 11 illustrates a typical boring job. Drills or end mills may be fitted into the end of the spindle in place of the long boring bar, or face mills may be bolted directly to the end of the spindle flange. This machine is used principally for precision toolroom work, although occasionally it is tooled up for work of a production nature.

FIG. 5. A High-Powered, 5 HM, Milling Machine Set Up in the Machine Tool Laboratory of the Department of Metal Processing for Wartime Research for the War Production Board and the U. S. Navy Department.

The work included a study of the types and shapes of high speed steel, cast nonferrous metal, and tipped-carbide milling cutters in which the nature of the wear, tool life, surface finish produced, and power required was determined when cutting a variety of metals at various combinations of speed, feed, and depth. The Profilometer and recording wattmeter are shown at the left. A single tooth is inserted in the face mill mounted on the face of an auxiliary flywheel, opposite the face of the 2-in. × 4-in. work held in the rigid fixture. The 20-hp motor mounted crosswise in the base permits a stronger column structure and makes both ends of the motor quickly accessible as well as insuring perfect motor ventilation. A multiple V-belt drive is used which is positive and silent. Twenty-four changes of speed ranging from 13 to 1,300 rpm arranged in geometrical progression are available, as are thirty-two feeds ranging from ¼ to 60 in. per min. A separate 5-hp motor furnishes feeds, and power rapid traverse at 150 in. per min. is furnished the table and 75 in. per min. for the knee and saddle, in both directions. A hypoid spiral-bevel-gear dividing head and tailstock are standard equipment with the universal machine.

The **planer-type** milling machine, Fig. 12, usually is constructed for heavy-duty work where straight surfaces are to be produced. The table travel resembles that of the planer, except that the planer-table travel furnishes the cutting speed, whereas that of the milling machine furnishes the cutting feed. Planer-type millers are used for a variety of kinds of milling, such as face milling, with heads mounted on either or both side columns or on the horizontal rail, and for gang milling, in which several cutters may be mounted on a single horizontal arbor, Fig. 12. The heads may be fixed or may swivel to adapt the cutter to beveled surfaces.



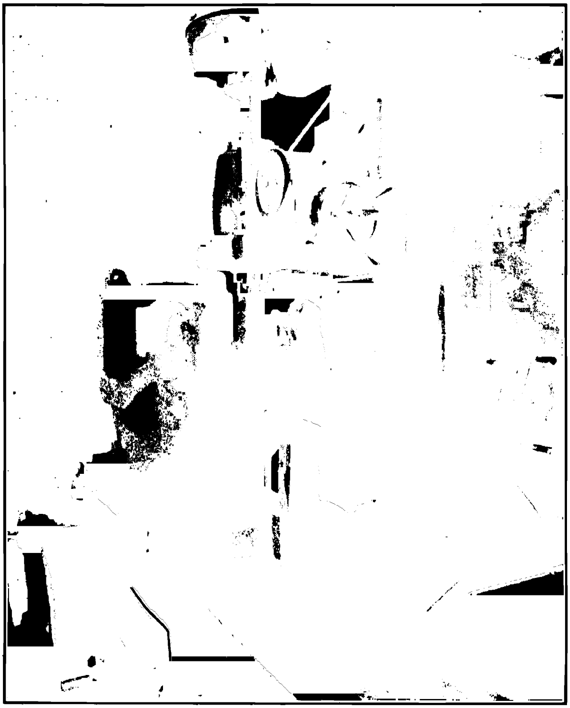
Courtesy Sundstrand Machine Tool Co.

FIG. 6. A Rear View of the Sundstrand No. 1 Rigidmil Production Milling Machine of the Fixed-Bed Type.

The table, hydraulically operated, may have a variety of single or continuous cycles of start, rapid traverse work to cutter, power feed through work, and rapid traverse to starting point. The 3-hp spindle motor shown in the foreground is attached to the head mounted vertically adjustable on the column face. The hydraulic 1-hp motor and pump are flange-mounted to the right side of the machine, and the pump is accessible from the front. The coolant pump is vertically mounted at the lower left.

Rotary millers are usually of the vertical-spindle type. These machines are provided with fixtures and are used for mass-production work in which the cutting is continuous, that is, there is no idle machine time. A rotary-type miller with two spindles mounted on a sliding head is shown in Fig. 13. The parts are loaded on one side of the machine, pass the roughing and then the finishing cutters, and return to the loading position where they are replaced.

In the **offset** miller, Fig. 14, the cutter or cutters are mounted on the short rigid arbor and rotate at the proper cutting speed. The work being milled is located on a fixture mounted on the table around the cutters and rotates in a direction opposite to the cutter but on an eccentric axis at the rate of proper feed. Offset milling is adapted for facing, slotting, straddle milling, sawing, milling to length, milling flats, and to some extent form milling. Forty gallons per minute of coolant are dumped onto the work and cutter to provide cooling, and wash the chips to the rear of the machine where they drop into the base, from which they are shoveled out periodically. Pick-off speed and feed gears are used, simplifying the construction.



Courtesy Reed-Prentice Corp.

Fig. 7. A Shank-Type Helical Mill Set Up in a Becker Vertical Milling Machine with Sliding Head for Facing the Inner Surface of a Cast-Iron-Frame Casting of a Punch Press.

The cutter is positively driven by a key at right angles to its axis. The clamping methods used are typical of job-shop or low-production work.

A **drum-type** miller having five horizontal spindles in four adjustable heads is shown in Fig. 15. The castings to be machined are mounted in the drum-type fixture which rotates continuously. Machines of this type may be made having two drum-type fixtures duplicated on the same shaft, giving the equivalent of two complete machines in one.

Thread milling machines are those machine tools designed to cut threads and worms. Milling cutters are used rather than single-point tools, Figs. 16 and 17.

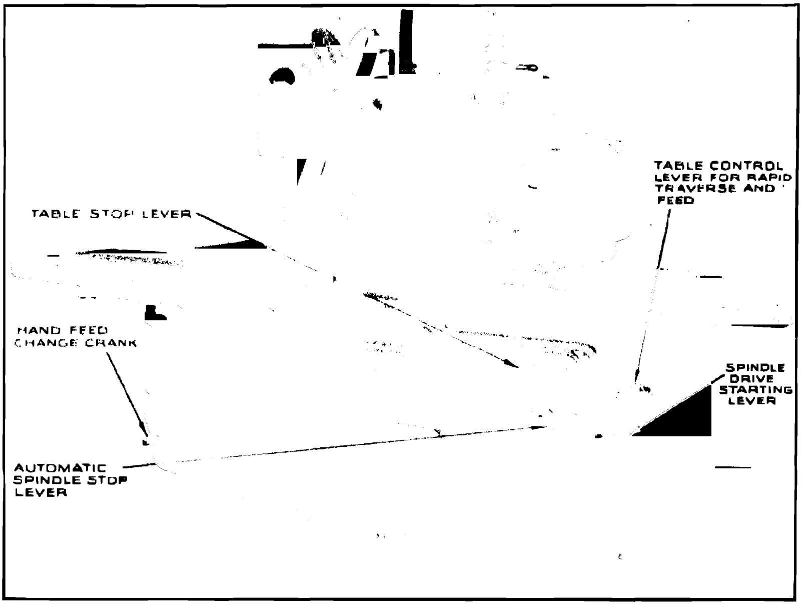


TABLE CONTROL LEVER FOR RAPID TRAVERSE AND FEED
TABLE STOP LEVER
HAND FEED CHANGE CRANK
SPINDLE DRIVE STARTING LEVER
AUTOMATIC SPINDLE STOP LEVER

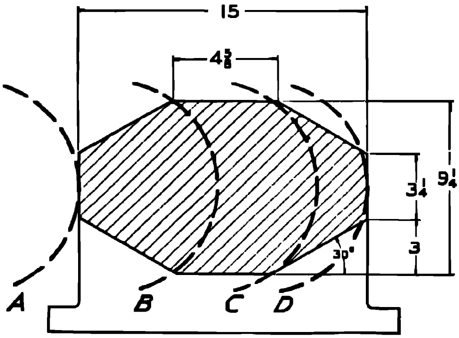
Courtesy Cincinnati Milling Machine Co.

FIG. 8. The 4-36 Cincinnati Plain Hydromatic Milling Machine.

The spindle is driven through a train consisting of b [illegible] contact. Eight speeds, ranging from 27 to 200 rpm, are provided as standard. The table is fed by hydraulic pressure with the hydraulic cylinder bolted directly to the underside of the bed. The feed may be varied automatically by trip dogs or cams to any value from 0 to 40 in. per min to meet the requirement of finish, production, or output desired. [illegible] feed may be changed to any desired value during the cut, as illustrated in Fig. 9. Power rapid traverse of the table of 300 in. per min is available.

This machine is set up with an inserted-tooth face-milling cutter to machine the irregular surface illustrated in Fig. 9. The feed is adjusted as the cutter advances to maintain constant power consumption as shown by the calibrated ammeter. The dial below the ammeter shows the value of the feed at all times during the cut.

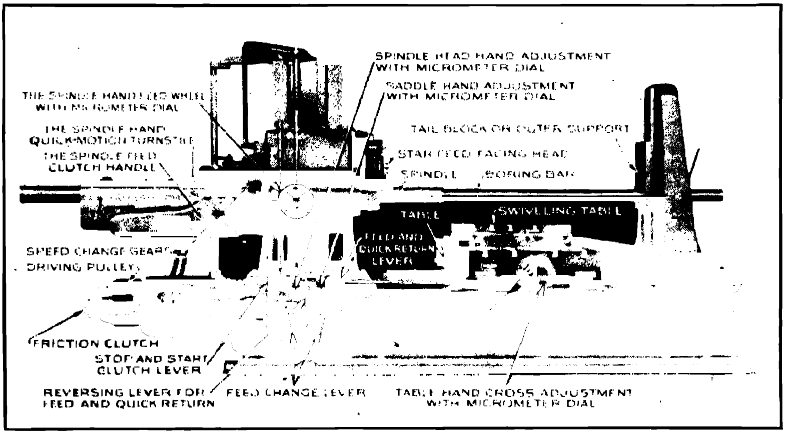
Threads may be cut in a lathe using a single-point threading tool; they may be chased in a lathe using a chaser having a number of points on the tool, as illustrated by the thread-chaser bit in Fig. V-11, in which the leading points are beveled off; or they may be cut by the use of taps and dies which correspond to thread chasing in which two, three, four, or more chasers are mounted on the interior of a cylinder



Courtesy Cincinnati Milling Machine Co.

FIG. 9. A Feeding Cycle on the Cincinnati Hydromatic.

The crosshatched area indicates the surface being face milled in Fig. 8. Instead of using a constant feed from cutter position *A* to *D*, requiring variable power consumption over the whole cut, a cam, shaped to conform with the nature of the cut taken, is bolted to the inner edge of the table and actuates a plunger controlling the rate of hydraulic feed. The feed is so controlled that the machine operates at a uniform full capacity of the motor for a shorter period of time for each cut. The feed is a maximum at position *A* of the cutter where the cut is short, gradually reduces to position *B* where the cut is greatest, constant to position *C*, and then increases gradually again to position *D* where the cut is again short. Considerable machining time may be saved by using the heavier feeds for the shorter cuts in order to maintain constant developed power. Rapid traverse is used to bring the table to position *A* and to return it to the starting point after reaching position *D*.


THE SPINDLE HAND FEED WHEEL WITH MICROMETER DIAL
THE SPINDLE HAND QUICK-MOTION TURNSTILE
THE SPINDLE FEED CLUTCH HANDLE
SPEED CHANGE GEARS
DRIVING PULLEYS
FRICTION CLUTCH
STOP AND START CLUTCH LEVER
REVERSING LEVER FOR FEED AND QUICK RETURN
FEED CHANGE LEVER
SPINDLE HEAD HAND ADJUSTMENT WITH MICROMETER DIAL
SADDLE HAND ADJUSTMENT WITH MICROMETER DIAL
TAIL BLOCK OR OUTER SUPPORT
STAR FEED FACING HEAD
SPINDLE
BORING BAR
TABLE
SWIVELING TABLE
FEED AND QUICK RETURN LEVER
TABLE HAND CROSS ADJUSTMENT WITH MICROMETER DIAL

Courtesy Lucas Machine Tool Co.

FIG. 10. The Lucas No. 43 Horizontal Boring, Drilling, and Milling Machine.

The machine has a 5-in.-diam. spindle and is equipped with a 36-in.-diam. circular swiveling table on base plate, and an auxiliary table for supporting long work. The swiveling table is graduated in half degrees and is mounted on a base plate with lock bolt for four positions, 90 deg apart, and elevating ball thrust bearings to facilitate swiveling. The Star Feed facing head is shown bolted to the face-plate or flange of the spindle sleeve. This has a radially feeding tool block so that diameters may be faced up to 30 in. Face mills may be bolted to the spindle sleeve flange when desired.

This machine is of the fixed-bed type and of the single-pulley drive, arranged for short-belt direct-connected motor drive, using a 15-hp constant-speed motor. There are eighteen feed changes ranging from 0.004 to 0.750 in. These feeds apply equally to the spindle in or out for 72 in., to the spindlehead and tail block up or down, to the saddle along the bed, and to the table across the saddle. Eighteen spindle speed changes, ranging from 7.5 to 220 rpm, are available. An auxiliary Hi-Speed Drive may be attached to provide seven additional speeds ranging from 264 to 860 rpm.

for die threading, or the exterior of the cylinder for tapping as described later under *Threading*.

In production work or where great accuracy and a good finish on the thread are desired, thread milling has been resorted to. By thread milling is meant the cutting of threads with a milling cutter which may consist of teeth mounted in a single diametral plane on the surface of a cylinder, such as the cutter, Fig. 16, or with a cutter which has rows of teeth, each row in the diametral plane, such as those illustrated in Fig. 17. Multiple-thread cutters have no lead. Long threads, such as worms and lead screws, are milled with single cutters, as illustrated in Fig. 16. This class of work is supported between centers, although it is sometimes necessary to hold one end of the shaft on which the thread is to be cut in a collet and support the other end on a center or by some type of rest.

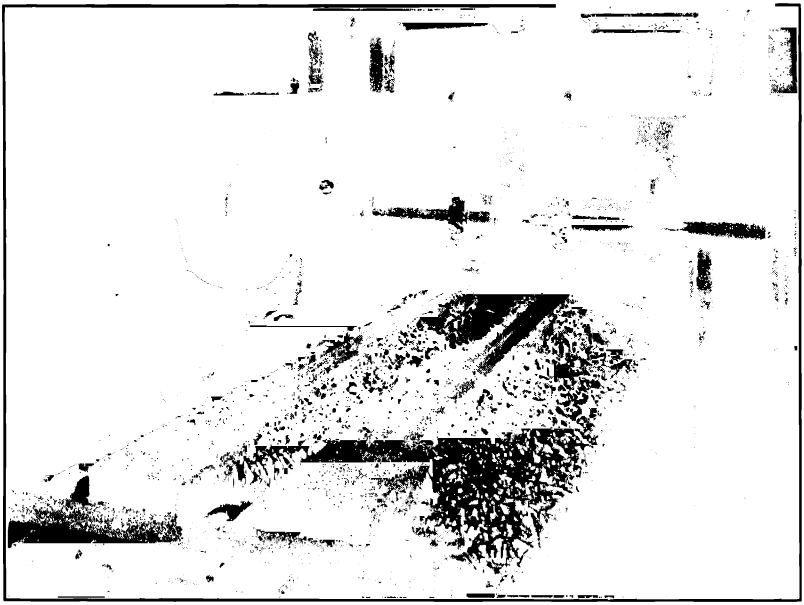
Courtesy Lucas Machine Tool Co.

FIG. 11. The No. 41 Lucas Horizontal Boring Machine with Dial Indicator Indexing Device Set Up to Bore Its Own Speed-Change Gearbox for Antifriction Bearings.

The head and table are adjusted to position with a hand crank so the dial indicators read zero with each combination of length gages shown on the table, which corresponds to the horizontal and vertical distances between the holes to be bored. This is the smallest Lucas machine, having a 3-in.-diam. spindle. It requires a 5-hp constant-speed motor.

The multiple-thread milling cutter, Fig. 17, is used when the length of thread to be cut is relatively short and rigid. By this method, threads may be cut close to a shoulder, either internally or externally.

A **planetary-type** milling and threading machine is shown in Fig. 18. It is used for internal or external threading and internal or external circular milling. For milling, the work is held rigidly stationary on the rest, or clamped to the tailstock, while the cutter, rotating at a high peripheral cutting speed, travels over the surface in a circular path. The cutter, which normally is approximately 20 per cent less for internal or greater for external milling than the diameter of the work being milled, is carried on a shaft in turn supported on two eccentric sleeves. The relative motion of these sleeves forces the cutter radially into the work at the beginning of the cut, remains fixed during the cut, and withdraws the cutter from the work at the end of the cut. The large worm wheel shown drives the inner eccentric sleeve but is mounted rotatably in the outer sleeve. When starting to machine, the worm



Courtesy Ingersoll Milling Machine Co.

FIG. 12. Channeling Two Locomotive Rods of 0.40–0.60 Per Cent Carbon Steel on an Ingersoll 100-hp, Inclined-Rail, Planer-Type Milling Machine.

Ingersoll 10-in.-diam. staggered-tooth channeling cutters are used, containing nine sets of teeth. Each cut is 3¼ in. wide by 1⅝ in. deep. The feed per minute is 4¾ in. Approximately 1.13 hp per cu in. of metal cut per min is developed by the motor. The cutters are flooded with an emulsion during the cut.

wheel is rotated, driving the inner sleeve which feeds the cutter radially to depth. After traveling a short distance, the outer sleeve is picked up and carried with the inner sleeve for one complete revolution, during which time the depth of cut is constant. At the end of one revolution, the worm wheel is reversed to the starting position, causing the inner sleeve to revolve in the outer sleeve, thereby withdrawing the cutter from the work. For threading, the cutter advances an amount equal to the lead of the thread during the angular sweep of one revolution. An internal threading job is illustrated in Fig. 19.

Courtesy Consolidated Machine Tool Corporation of America.

FIG. 13. A Type C-66A Newton Continuous Vertical Miller with a 48-in.-diam. Table.

On the rotating table are constructed fixtures for holding the work to be machined. The operator, standing in the foreground, releases the pieces from the fixtures as they come from the finishing cutter, reloading with castings to be machined.

Diesinking may be done on a vertical miller with manually operated feeds to the table.

An **automatic diesinking** or profiling milling machine is illustrated in Fig 20. The cutter, carried on a vertically adjustable horizontal spindle, opposes the work which is mounted on a vertical plate on a horizontally adjustable table. The movements of the cutter and work are automatically controlled by means of a finger on a higher horizontal spindle which is in contact with the templet on a vertical plate also supported on the table. An illustration of a diesinking job is shown in Fig. 21. This machine also may be used for general milling work without the automatic feeding device.

Courtesy Oesterlein Machine Co.

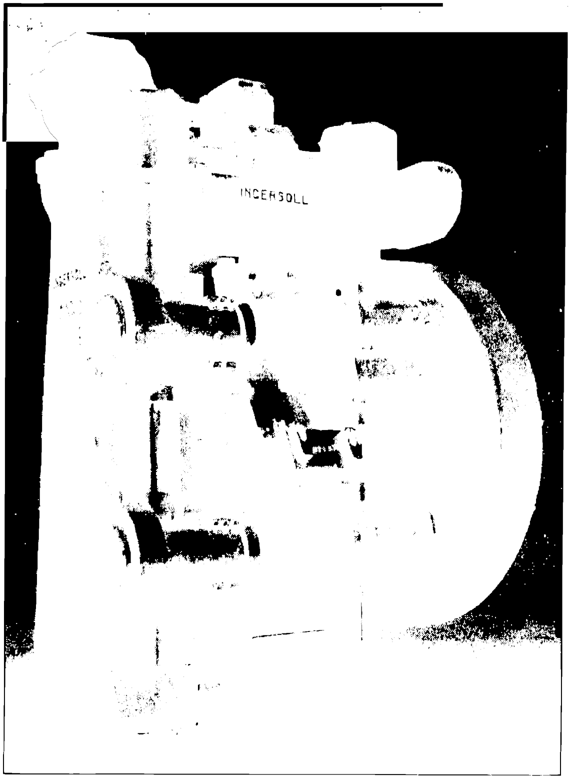
Fig. 14. Oesterlein 48-in. Standard Offset Miller.

Equipped with three sets of double-deck fixtures designed to mill two consecutive operations on a valve lever pin support in the plant of the International Harvester Co. This is a hand-clamping master fixture arranged with special jaws for the part. In the upper deck fixtures, the part is milled to length by being faced on both ends by inserted-teeth face mills and is slotted. In the lower fixture, the slotted boss is faced on both ends, making five operations in two revolutions. One hundred and sixty complete parts per hour with a feed of 7½ in. per min are obtained.

Milling-Machine Drives for Spindle Speeds

Nearly every milling machine has some means of providing various speeds of rotation of the spindle or cutter. In general, milling machines are power driven by two methods: the **step-cone-pulley drive** and the

constant-speed or **single-pulley drive,** as described under *Lathes.* The range of speed varies with different classes of millers and work to be done. Small machines, in which small-diameter cutters are to be



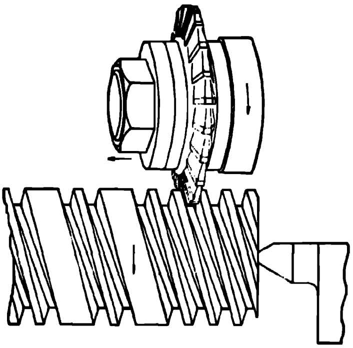
Courtesy Ingersoll Milling Machine Co.

FIG. 15. A Five-Spindle Drum-Type Milling Machine for Milling the Top and Bottom of Cylinder Blocks.

The spindleheads are adjustable vertically, making it possible to change the radius of cut circles if the machine is to be used for other operations. The drum rotates continuously, the castings being clamped to the rotating fixture on the far side of the machine. They come in contact first with the two upper opposed spindles which rough face the surfaces, after which they are finished with the cutters on the lower head.

used, have a series of high speeds, while the large machines for heavy-duty work, using large-diameter cutters, have a series of low speeds.

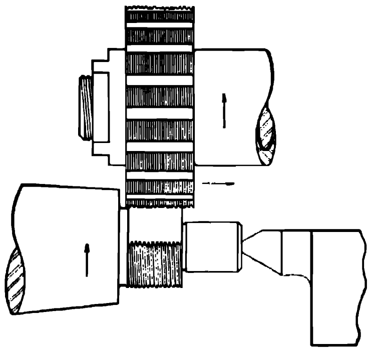
The **constant-speed, single-pulley** or **geared-type** drive is the one used on most of the modern machines. This is a distinct improvement over the cone-type drive, inasmuch as accurate and strong train gears are used which can be mounted inside the column of a machine where they are protected from dirt and injury and where they are automatically and continuously lubricated. The driving pulley of the machine may be driven by belt directly from a main drive shaft, a jackshaft, or directly from a motor placed remotely or built into the machine.



Courtesy Lees-Bradner Co.

FIG. 16. Relation of Single-Thread Milling Cutter and Work for Milling a Thread on a Worm or Lead Screw.

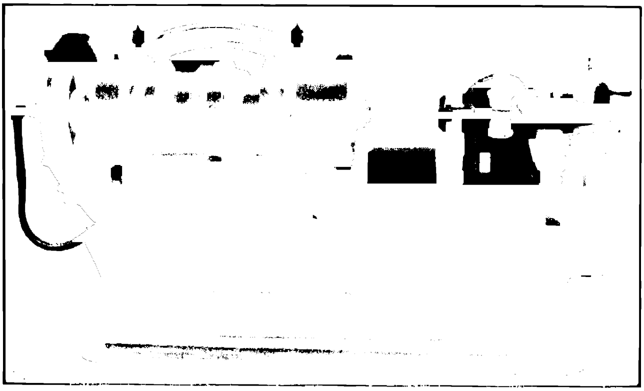
The cutter rotates in the direction of the arrow to give proper cutting speed, and is fed parallel to the axis of the thread an amount equal to the lead for each revolution of the screw. The work may be mounted between centers as shown, or held in a collet while being milled. It rotates in the same direction as the cutter to provide the cutting feed.



Courtesy Lees-Bradner Co.

FIG. 17. A Setup Showing the Relation of the Multiple-Thread Milling Cutter and the Work Being Threaded.

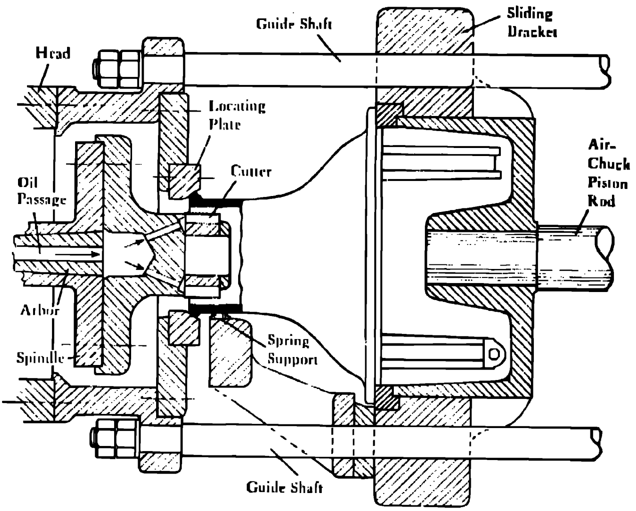
The cutter is first fed toward the work to depth of cut, after which the work rotates one complete revolution while the cutter moves along the work an amount equal to the thread lead. At the end of one revolution, the cutter is withdrawn.



Courtesy Hall Planetary Co.

FIG. 18. A Planetary Type Milling Machine.

A sectional view of the No. 2 Cincinnati plain milling machine, showing the arrangement of gears by which power is supplied to the spindle from the motor in the base through the constant-speed sprocket wheel at the lower left, is shown in Fig. 4. The multiple-disk clutch and brake for starting and stopping the machine are shown within the column to the right of the sprocket wheel. Various speeds are obtained by engaging different driving gears of the train. Machines of this type may be secured having a standard speed range for general work, or equipped with a low series or high series to suit special requirements. The milling machine shown in Fig. 4 is provided with sixteen speeds ranging from 20 to 500, while the one in Fig. 5 has the unusually large number of twenty-seven speed changes ranging from 15 to 1,500 rpm. This has been designed to provide proper speeds for cutters of large or small diameter and to provide high peripheral speeds made possible by the use of the new sintered-carbide cutting tools.

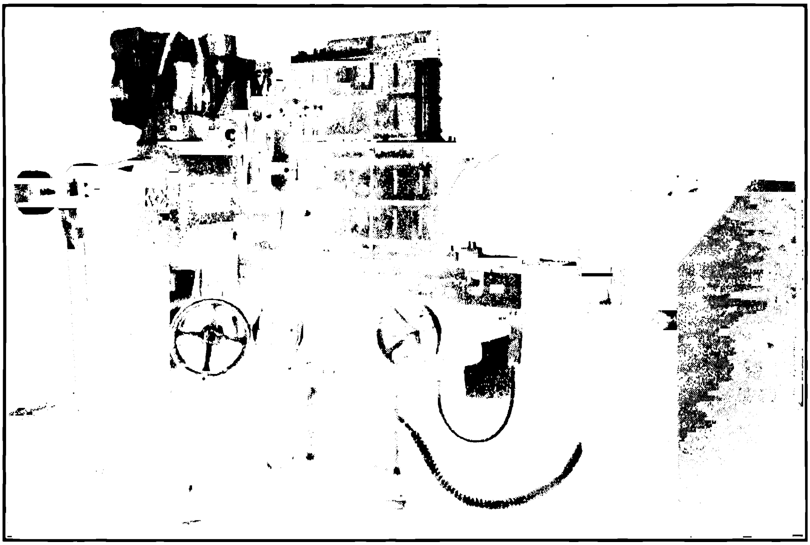


Courtesy Hall Planetary Co.

FIG. 19. Planathreading a Malleable Cast-Iron Differential Housing for Bearing Retainers of Bevel Pinion Shaft.

The housing is located by dowel pins on a sliding head which is ready to be forced by an air-chuck piston rod against a locating plate in the spindle. The diameter of the cut is 3½ in., and the thread milling time from floor to floor is 50 sec.

Machines built primarily for mass production, such as the Oesterlein tilted offset miller shown in Fig. 14, have the train of gears for speeds so constructed that one pair, known as **pick-off gears**, may be replaced easily by another pair for the purpose of changing speeds if the machine setup is to be changed. This simplifies the machine construction and reduces its initial cost. Usually only one set of pick-off gears for speeds or feeds need be purchased with the machine for a specific setup.



Courtesy Keller Mechanical Engineering Corp. and Pratt and Whitney Co.

FIG. 20. An Automatic Diesinking Miller.

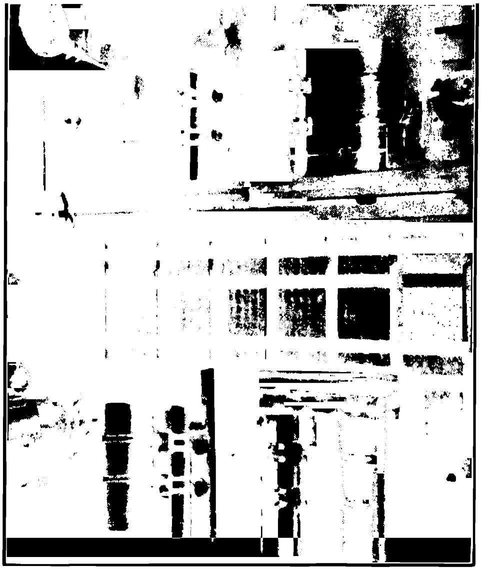
It is provided with a two-piece angle plate work-holding fixture, as well as the electrical control device to reproduce in steel, mounted on the lower plates, the shapes of templets or depressions. An end mill cutter is shown on the right-hand end of the lower horizontal spindle. A feeding finger on the upper spindle contacts with templets or impressions to be reproduced. The templets are mounted on the upper angle plate.

Milling-Machine Drives for Feeds

The feed of the milling machine is the movement toward the cutter of the table on which the work is mounted.

Feed movement: On knee- and column-type machines, there are three possible directional movements of the table, namely: **longitudinal,** in which the table is fed lengthwise on the saddle; **transverse, in** which the table and saddle are fed crosswise on the knee; and **vertical,** in which the table, saddle, and knee are moved vertically on the column. Vertical-spindle machines may have, in addition to the above, **a vertical feed** to the spindle, and all milling machines equipped with a **rotary** table or drum have **rotary feeds.**

Feeds, hand and power: Any of the above feeds may be operated by hand or power. On small machines such as bench millers and hand millers all feeds usually are operated manually through a rack and lever-driven pinion, or by a crank and screw. Many older knee-type millers for toolroom work, Fig. 1, have hand and power longitudinal feed, but only hand transverse and vertical feeds. The more modern knee-type millers may have hand and power feed and power rapid traverse in all directions. The fixed-bed-type millers, as illustrated in Fig. 8, have power feed and power rapid traverse longitudinally for the table, and vertically for the head. Vertical-spindle machines for light work may have some or all directional feeds only manually operated, while the larger sizes, Fig. 7, usually embody power feeds. The modern horizontal, boring, drilling, and milling machines, as illustrated in Fig. 10, usually are provided with hand and power feeds to the table, head, and spindle. Large planer-type millers are equipped with power feeds and power rapid traverse for the longitudinal travel of the



Courtesy Keller Mechanical Engineering Corp. and Pratt and Whitney Co.

FIG. 21. A Pair of Lifting-Lever Dies Being Cut in Heat-Treated Steel on a Templet-Type Diesinker.

A pair of existing dies as shown above were used as masters. All cavities, locks, gates, and flat surfaces were cut, as shown in the lower part of the picture, from solid blocks of steel, no preparatory work having been done before the die blocks were mounted on the machine. The finger in contact with the master has the same form as the cutter. The total cutting time for machining the pair of dies from the flat surface blocks was 26½ hr.

table, and the various heads may have independent power feed and power rapid traverse as desired.

The feed is obtained in the rotary-type millers by rotating the table carrying the work uniformly and continuously, while the cutter rotates to provide the cutting speed. In thread milling machines, power feeds are used to insure uniformity and accuracy of the cut.

Feed drives: The tables carrying the work to be milled may be power fed **mechanically** or **hydraulically.** A lead screw is usually employed in the mechanical drives, although the worm and rack are used in the large Sellers planer-type miller. Power feeds may be obtained by belt drive from a step-cone pulley on the spindle, by belt and step-cone pulley and gearbox combined, Fig. 1, or, in the more modern machines, entirely by a train of gears as discussed below under *Feed Designation*.

In modern machines, all feed-change gears are built into the machine. In mass-production machines, the train of gears, for feeds as well as for speeds, contains a pair of **pick-off gears** which may be replaced easily by another pair if the machine setup is to be changed.

Since 1922 there has developed a great and rapidly increasing trend toward the use of **hydraulic-feeding mechanisms** on metal-cutting and forming machines. These are discussed later under *Hydraulic Feeds*.

Milling machines employing the hydraulic drive are illustrated by the Cincinnati Hydromatic in Fig. 8. Hydraulic feeds permit very flexible machining cycles in which power rapid traverse is possible through the nonmachining part of the stroke, and feeds may be changed quickly or gradually during the cut, Fig. 9, in which case the object is to keep the machine and motor operating at uniform full capacity even though the amount of metal being removed by the cutter varies at different points. This shortens the time required to perform the operation.

Feed designation: There are two feed systems applied to milling machines in general use — feed in thousandths of an **inch per revolution of the spindle** and feed in **inches per minute.** Standard practice is to make cone-driven machines, Fig. 1, with the feed mechanism driven from the spindle and reading in thousandths of an inch per revolution of the spindle. When the spindle speed is increased or decreased, the travel of the work is changed in proportion, but the feed in inches per revolution of the spindle remains constant.

Single-pulley or constant-speed-drive milling machines, as well as hydraulically driven machines, designate the feed or table travel to read in inches per minute. In the geared machine, the feed gears are driven from the constant-speed shaft rather than from the spindle and are, therefore, independent of the spindle speeds. Hydraulic feeds also are independent of the spindle speeds. This system predominates, inasmuch as most of the machines of today are of the single-pulley drive or arranged for direct-motor drive. This is discussed further under *Definitions of Cutting Speed, Feed, etc.*

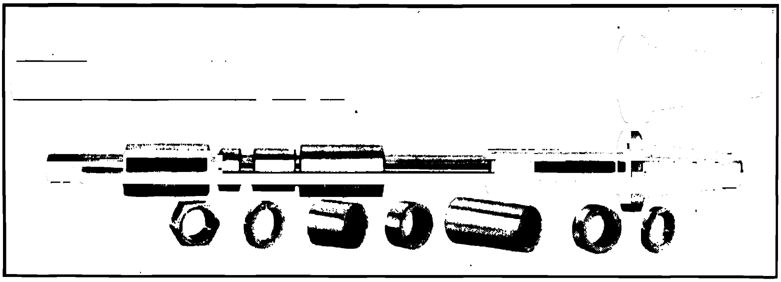
MILLING-MACHINE ACCESSORIES

Standard equipment accompanying various milling machines varies somewhat with the size and type. The Cincinnati plain milling machine, shown in Fig. 3, provides, as standard equipment, arbor supports —one with adjustable bushing and provided with lug for braces and one with adjustable bushing for pilot end arbors— an arbor tightening rod or draw-in bar, belt guards when belt drive is used, necessary wrenches, an 8-gal-per-min geared cutting-fluid pump, and a plain vise. For the universal millers of this same type, a universal three-jaw chuck and flange, a swivel vise in place of a plain vise, and the universal dividing head are provided. The chuck, vise, and dividing head are of sizes proportionate to the size of the milling machine.

The countershaft is usually standard equipment with the step-cone-pulley-drive machine. An extra charge is made, however, if the single-pulley-drive machine is to be arranged for direct-motor drive, and the customer pays extra for the motor and starter.

Vises: Plain vises, Fig. 3, are low and rigid. Universal or swiveling vises are illustrated in Fig. 2. For some classes of work **circular tables** are desirable, some of which are hand operated, as shown in Fig 10, or they may have power feed attachments. The circular tables of the rotary millers are standard equipment with those types of machines.

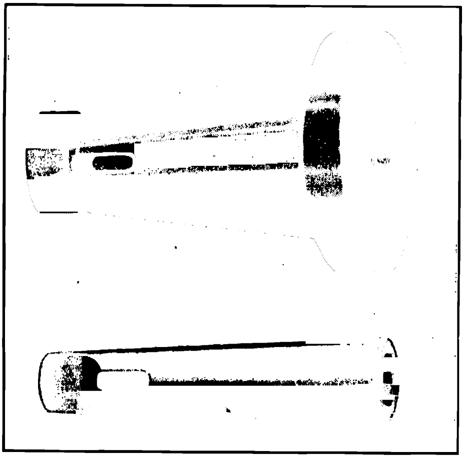
Arbors, adapters, and collets are provided to carry the cutters used in milling. The spindle of the machine is arranged to receive the shanks of arbors, Fig. 22, of collet and cutter adapters, Fig. 23, or of chuck adapters in which the nose is threaded like the spindle of a lathe to receive the threaded flange of a chuck. The shank of the arbor or adapter is held in the standard machine spindle by a draw-in bar or bolt extending through the spindle. It is positively driven by the two keys screwed to the end of the spindle, which engage the slotted flange of the arbor. The cutter is keyed to the arbor and in addition is held in a definite place by means of the various spacers shown in Fig. 22. Additional spacers from 0.001 in. thick up may be obtained. The two hardened and ground sleeves serve as bearings in the arbor supports hung on the overarm to provide rigidity to the arbor and the cutter. These arbors are furnished in different diameters and lengths to suit the requirements of the different types and sizes of milling machines.



Courtesy Cincinnati Milling Machine Co.

FIG. 22. The Original Forging and Finished Type B Arbor with the Self-Releasing Taper of 3½ in. per ft.

Two ground sleeves for arbor supports and five spacers are shown on the arbor, together with additional spacers and retaining nut shown below. There are ten sizes of taper ranging by fives from No. 5, which is ½ in. diam. at the large end by ⅝ in. long, to No. 60, which is 4¼ in. diam. by 6⅜ in. long.



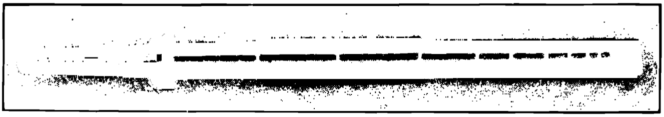
Courtesy Cincinnati Milling Machine Co.

FIG. 23. The Standard Collet Adapter and Collet.

The collet adapters, Style E, have either a No. 9 Brown and Sharpe inside taper or a No. 4 Morse inside taper. The outside taper fits the spindle. The outside tapers of the collets to fit the adapter are No. 9 Brown and Sharpe for Style J, or No. 4 Morse for Style K. The inside tapers of the collets are No. 4, 5, and 7 Brown and Sharpe for Style J, and No. 1, 2, and 3 Morse for Style K. This permits the use of any standard taper-shank twist drill, arbor, or milling cutter in milling-machine work.

Up to the time of the adoption of the self-releasing taper of 3½ in. per ft (ASA B5.10) in the spindle, Fig. 22, milling-machine spindles were constructed with a Brown and Sharpe self-holding taper. The style E arbor for the old-style machine, having a threaded-nose spindle, is shown in Fig. 24. The old style F arbor is shown in Fig. 25.

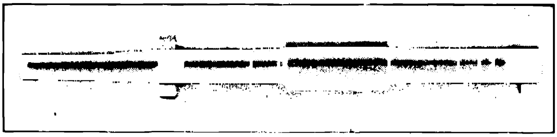
In order that wire, small rods, and straight-shank tools may be used interchangeably in milling machines, the collet holder for the old-style spindle is provided, as shown in Fig. 26, with a spring chuck and cap nut.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 24. Style E Arbor with Brown and Sharpe Taper Shank.

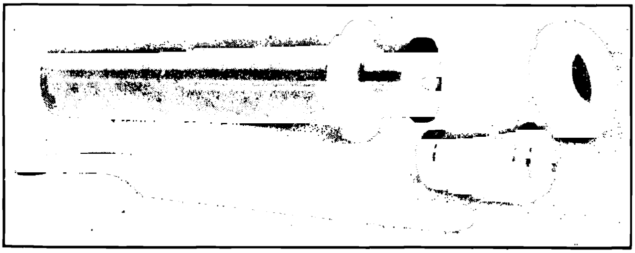
16¼- to 35-in.-long shoulder to nut for use on old-style Brown and Sharpe milling machine, having threaded-nose spindles. Two bearing sleeves with spacers are assembled on the arbor.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 25. Style F Arbor.

Twelve- or 15-in.-long shoulder to nut for use on old-style milling machine, having taper-nose spindles. The arbor is held in the spindle by a draw-in bolt and is driven positively by keys. Seven spacers, one sleeve, and one nut are assembled on the arbor.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 26. Spring Chuck and Collet Holder for Brown and Sharpe Taper Milling-Machine Spindles.

For use in spindles of either taper or threaded nose for holding wire, small rods, straight-shank drills, and mills, etc. The spring collet is held in place by the cap nut that forces it against the taper seat and closes the chuck concentrically. The collet holders also are made with the new standard taper.

Dividing head: The object of the dividing head, often called the spiral or universal indexing centers, is to rotate a piece of work through a certain number of degrees or a certain fractional part of a complete circle for purposes of graduating or machining the part. There are three principal types of dividing heads: the single dial, plain, and universal.

The **single dial** or plate head, for simple, rapid indexing, consists of a headstock and tailstock similar to those in Fig. 2. The spindle of the headstock carries an index plate or disk, the periphery of which is graduated in degrees or provided with notches so the spindle carrying the work may be rotated through a certain part of a circle to machine, successively, the several faces of the part. Twenty-four divisions (as well as 2, 4, 6, 8, and 12) also may be indexed directly by using the plate C, Fig. 27, with the worm out of mesh with the worm wheel.

The **plain** dividing head is provided with interchangeable index plates carried on a worm shaft, the worm of which engages a worm wheel mounted directly on the head spindle. Each index plate is provided with several circles each divided into a different number of spaces by equally spaced small holes. This type of head also may employ a graduated plate fixed directly on the spindle for direct or rapid indexing. When the plate on the spindle is used, the worm is disengaged from the worm wheel.

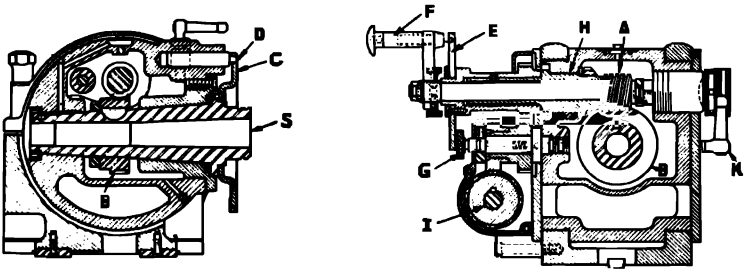


FIG. 27. A Longitudinal and Transverse Section of the Brown and Sharpe Universal Dividing Head.

This shows how the spindle *S* is driven through the forty-to-one worm-and-worm-wheel drive by the index crank *F*. For *rapid indexing* of taps, reamers, gears having a small number of teeth, etc., the worm *A* may be drawn out of mesh with the worm wheel *B* to allow the spindle to be turned by hand. The large index plate *C* is graduated and is locked in each position by the pin *D*. For *plain indexing*, the index plate *E* is fixed in its position by a pin on the knurled wheel *G*. The spindle is then turned by rotating the crank *F* through a determined number of spaces of a given circle on the index plate. When *differential indexing* is used, the index plate *E* is made free to rotate by removing the lockpin *G* and connecting the spindle *S* and the stud *I* by a train of gears.

The **universal** dividing head, as illustrated in Fig. 2 and Figs. 27–30, incl., also has the single plate C, Fig. 27, on the spindle and the interchangeable plates on the worm shaft. The spindle may be swiveled from below the horizontal to beyond the vertical as read on a scale graduated in degrees. The tailstock center may be elevated above or lowered below the center of headstock for cutting on a taper, and it may be swiveled slightly in the vertical plane of the headstock center for milling drill flutes, tapers, reamers, etc.

The universal dividing head usually consists of a headstock, tailstock, and center rest, together with index plates, necessary change gears, and a segment, or adjustable gear plates shown in Fig. 30. The universal dividing head may be used for cutting straight-formed grooves, such as cutting spur gears with a form cutter, Fig. XIV-5, in which the gear blank is mounted on a mandrel supported between the centers, or for the purpose of milling helical grooves when the table of the universal miller is swiveled to the proper angle.

There are a number of different types of dividing heads as manufactured by the various companies. The Vinco Optical Master Inspection Dividing Head, shown as No. 4 in Fig. XVIII-41, guarantees the checking of angles to an accumulative error of not more than 2 sec of arc. This head has only graduated scales. The main scale on the spindle provides a setting to the nearest 20 min of arc. A 40X microscope shows a second scale which divides 1 deg into 10 min of arc. A micrometer thimble has 10 graduations of 1 min each on its periphery, and the micrometer barrel divides each minute into 10 equal spaces on one side and 60 sec on the opposite.

The Brown and Sharpe dividing head is shown in longitudinal and transverse section in Fig. 27. The transverse section at the left shows the worm wheel *B* attached directly to the spindle *S*. At the right, the worm *A* driven by the crank *F* is shown engaged with the worm wheel *B*.

Indexing: Three kinds of indexing are possible with the universal head: plain or simple, compound, and differential.

Plain indexing may employ the single plate *C*, Fig. 27, fixed to the spindle, to rotate the spindle through a desired number of spaces of the circle while the worm is disengaged from the worm wheel. The plate is graduated into 24 equal divisions for direct or rapid indexing. Plain indexing also may be accomplished by using a multiple circle index plate as *E*, Fig. 27, mounted on the worm shaft. Also see Fig. 28. The index plate *E* is fixed in a given position by the pin *G* so that it cannot rotate. The radius of the crank *F* is adjusted so that the crankpin engages the holes of a desired circle in the plate *E*. By turning the crank *F*, moving the crankpin from one hole in the plate *E* to another, the worm *A* turns the worm wheel *B* which, in turn, rotates the spindle *S* carrying the work.

A relation between the motion of the crank and that of the work mounted on the spindle, for plain or simple indexing, is found as follows:

Let R = the ratio of the worm wheel to the worm, usually 40 to 1.
T = the number of divisions required, such as the teeth in the gear to be cut.
N = the number of holes in a circle of the index plate.
n = the number of spaces in a circle to be indexed.

With $R = 40$, one complete turn of the crank (N holes) is required to index one tooth of a 40-tooth gear; then $R/T = 40/40 = 1$. Also, one-half turn of the crank ($N/2$ spaces) is required to index one tooth of an 80-tooth gear; then $R/T = 40/80 = 1/2$. Also, one-third turn of the crank ($N/3$ spaces) is required to index one tooth of a 120-tooth gear; then $R/T = 40/120 = 1/3$.

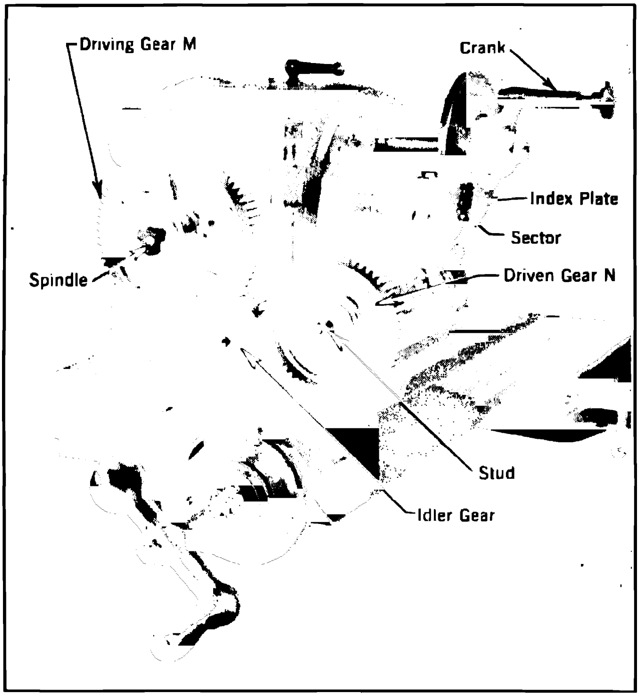


FIG. 28. The Brown and Sharpe Dividing Head Set Up for Differential Indexing.

As the indexing crank is turned to index the work carried on the spindle of the head, the index plate is rotated, being driven from the moving spindle through the three gears shown in the foreground. The setup shown calls for two gears and one idler.

The 1, ½, and ⅓ above are the part of a complete turn of the crank and may be expressed as n/N; then the general formula for plain indexing is $R/T = n/N$. R usually equals 40, so that $R/T = n/N$ becomes $40/T = n/N$. Q.E.D.

The Brown and Sharpe dividing head is equipped with three plates having circles with holes or spaces as follows:

Plate No. 1: 15–16–17–18–19–20.
Plate No. 2: 21–23–27–29–31–33.
Plate No. 3: 37–39–41–43–47–49.

Example 1: Plain Indexing. It is required to set up a dividing head to form the teeth of a 48-tooth gear and to select the proper circle to be used and the number of spaces to be indexed. T is 48 and R is 40, and the formula becomes $\frac{R}{T} = \frac{40}{48} = \frac{n}{N}\cdot$ Values of n and N are assumed, so $\frac{n}{N} = \frac{40}{48} = \frac{5}{6}\cdot$ Of all the circles available, only the 18 is divisible by the denominator 6. Therefore, the formula may become

$$\frac{40}{48} = \frac{5}{6} = \frac{5}{6} \times \frac{3}{3} = \frac{n}{18}$$

in which n is found to be 15. Therefore: $N = 18$ and $n = 15$, and 15 spaces of the 18-hole circle would be indexed to form each of the 48 teeth of the gear. The radial fingers of the sector over the index plate, shown in Fig. 28, are adjusted to include the 15 spaces to permit a quick and accurate indexing for each cut. The sector is independent of the crank and plate, but rotates with the plate as the crank is turned.

By **compound indexing** is meant the using of two different circles of one index plate in order to obtain a crank movement not obtainable by plain indexing. The crankpin is engaged in circle N_1 and the lockpin is engaged in circle N_2 of the index plate. Indexing is obtained by moving the crank n_1 spaces in the circle of N_1 holes and then withdrawing the lockpin and moving the plate and crank together, forward or backward, through n_2 spaces in the N_2 circle, so that $\frac{R}{T} = \frac{n_1}{N_1} \pm \frac{n_2}{N_2}\cdot$ This method is little used today, as it has been replaced by differential indexing.

Differential indexing is used when the problem cannot be worked by plain indexing. In differential indexing, the lockpin G, Fig. 27, is not engaged with the index plate which is screwed to a sleeve about the crank spindle. This sleeve carrying the plate may be rotated by a gear train from the stud I. The stud I and spindle S, Fig. 27, are connected by a train of gears, as illustrated in Fig. 28, in which M is the driving gear on the spindle and N is the driven gear on the stud. As the crank is turned, the spindle is rotated by the worm W. The spindle S, in turn, carries the driver gear M, Fig. 28, which drives the driven gear N through an idler gear. The lower shaft turns the sleeve carrying the index plate through a train of helical and spur gears of unit ratio. If the crank is to be moved from hole number 0 to 18 (18 spaces) by differential indexing, hole 18 will be moved a short distance forward or backward by the train of gears M/N, Fig. 28, whose value is x as the crank is turned, so that the crank actually will be moved something more or less than 18 spaces. This is doing nothing more in principle than modifying the value of the worm and worm-wheel ratio by a small amount x. The formula for plain indexing

$$\frac{R}{T} = \frac{n}{N}$$

may be modified then to

$$\frac{R \pm x}{T} = \frac{n}{N}$$

which is the general formula for differential indexing, in which x is the value of the train of gears required to drive the index plate from the spindle. The gears in the numerator are the drivers, and those in the denominator are the driven. The idler gear or gears change only the direction of rotation of the index plate and do not affect the value of the gear train. The center distance between the spindle and stud, Fig. 28, is fixed. The idlers may serve to reverse direction of rotation or to fill in between the driver and driven gears.

Rules for determining the number of idlers to be used with the train of gears are as follows:

1. If x is plus, the plate should rotate in a direction opposite to the crank. If 2 gears are required in the train (simple gearing), then 2 idlers are necessary.
2. If x is negative, the plate rotates in the same direction as the crank. If 2 gears are required, then 1 idler is necessary. This setup is shown in Fig. 28.
3. If x is plus and 4 gears are required (compound gearing), only 1 idler is necessary. See idler gear Z in Fig. 30.
4. If x is negative and 4 gears are required, no idler (or 2) is necessary. See Fig. 29.

The Brown and Sharpe dividing heads for differential indexing are equipped with a set of 12 gears from which the train x is made, having 24, 24, 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100 teeth, respectively.

Example 2: Differential indexing, simple gearing. Find N, n, the train of gears necessary and the number of idlers required to index 96 divisions. The general formula for differential indexing is $\frac{R \pm x}{T} = \frac{n}{N}$. Then $\frac{40 \pm x}{96} = \frac{n}{N}$ when $R = 40$ and $T = 96$.

Determine n/N which will plain-index some even number near 96, and then solve for a train of gears x to rotate the plate to index 96 accurately, as follows: $\frac{40}{96}$ equals approximately $\frac{40}{100} = \frac{2}{5} = \frac{n}{N}$. Five is divisible into circles having 15 and 20 holes.

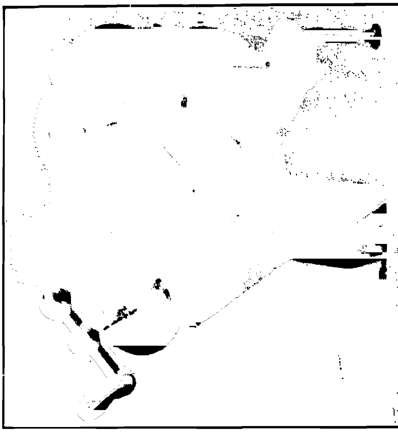


FIG. 29. The Brown and Sharpe Dividing Head Set Up for Differential Indexing.

In this, four gears are used to drive the index plate from the spindle, two of the four gears being keyed to the intermediate shaft and serving as an idler. The setup, however, calls for four gears and no idler.

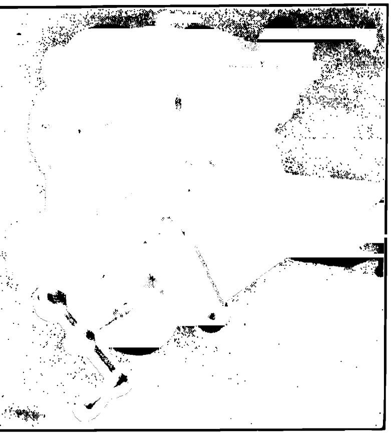


FIG. 30. The Brown and Sharpe Dividing Head Set Up for Differential Indexing.

Four gears and one idler, *z*, are required in the train of gears for $T = 201$,

$$\frac{M}{P} \times \frac{O}{N} = \frac{24}{72} \times \frac{24}{40}$$

Select 20; then $\frac{40}{100} = \frac{n}{N} = \frac{2}{5} = \frac{8}{20}\cdot$ Then 8 spaces of a 20-hole circle will plain-index 1/100 of a circle or 1 tooth of 100 to be formed.

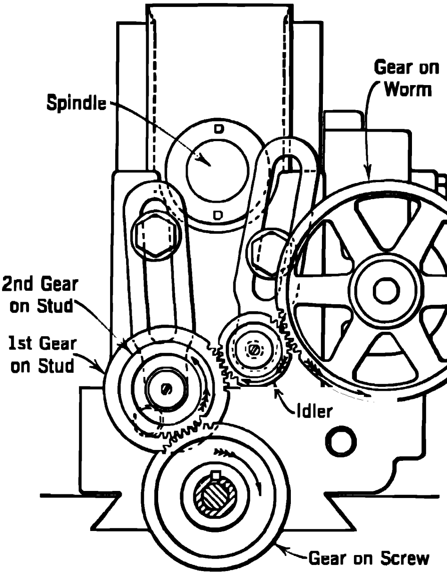
Now determine from the general formula the value of x required to modify the plain indexing for 100 divisions to differential indexing for 96 divisions. Then $\frac{40 \pm x}{96} = \frac{8}{20}\cdot$ $\pm x = \frac{96 \times 8}{20} - \frac{40 \times 20}{20} = \frac{768 - 800}{20} = -\frac{32}{20}\cdot$ The fractional value of $x = -(32/20)$ must be modified to agree with the number of teeth in the change gears available, as there is no 20-tooth gear. $-\frac{32}{20} \times \frac{2}{2} = -\frac{64}{40}$, $-x = \frac{64}{40}$ which is satisfactory. The 64-tooth gear is the driver on the spindle corresponding to M, Fig. 28, and the 40-tooth gear is the driven, as N. Then $\frac{M}{N} = \frac{64}{40}\cdot$

The crank would be rotated through 8 spaces of a 20-hole circle to index 1/100 of a complete circle by plain indexing when $R = 40$. If 1/96 of a circle is to be indexed, the crank would have to rotate a little farther than 8 spaces because 1/96 of a circle is a greater distance than 1/100. It is seen, therefore, that the train of gears would have to rotate the index plate in the same direction as the crank is turned.

As x is minus and 2 gears are used, the plate will rotate with the crank. From rule 1, one idler will be necessary on the reversing gear plate, as shown in Fig. 28. Sometimes the value of x cannot be satisfied by two gears as 64/40 above. Then four gears must be used, as shown in Figs. 29 and 30. If the fraction for x cannot be satisfied by 2 or 4 gears, assume another value for n/N and solve again for x.

A chart, which recommends the indexing plate and circle and the drivers, driven, and idler gears to be used, accompanies every dividing head.

Helices (often called spirals) also may be cut by the use of the dividing head, Fig. 2. Helices that are most commonly cut on milling machines embrace helical gears, helical mills, counterbores, and twist drills. Worms also may be cut with some dividing heads, while other heads require the aid of a vertical spindle, etc. In cutting helices, the dividing-head spindle is rotated uniformly while the table advances the work into the cutter. The spindle *B* of the dividing head, Fig. 27, is driven by the worm *A* connected by unit-ratio gears to the worm shaft *I*. The worm shaft *I* is connected by a train of change gears (the same set of gears as used in differential indexing) to the table longitudinal-feed lead screw, as illustrated in Fig. 31, which shows four gears in the train and one idler. The four gears are known as the gear on screw, first gear on stud (as it is the first to be put on), second gear on stud, and gear on worm. The gear on screw and the first gear on stud are the drivers, and the others are the driven gears.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 31. An End View of the Dividing Head and the Table of the Milling Machine, Set Up for Left-Hand Helical Milling, Showing the Four Gears and One Idler Used in Transmitting Power from the Gear on the Table-Feed Screw to that on the Worm of the Dividing Head.

The feed screw of the table has, say, 4 threads to the inch; also 40 turns of the worm make 1 turn of the dividing-head spindle. Therefore, if change gears of unit ratio are used, the work will make a complete turn while it is moved by the lead screw longitudinally 10 in. That is, the helix will have a lead of 10 in. and it is so designated, rather than as having a pitch of $\frac{1}{10}$ turn per in. This constitutes the lead of the machine, and by using different combinations of change gears the ratio of the longitudinal movement of the table to the rotary movement of the work can be varied.

When the change gears have unit ratio, a helix having the lead of the machine (10 in.) is produced. If one driven gear is double the diameter of the other three gears, a helix with a lead of 20 in. or twice the lead of the machine is produced; if both driven gears are twice the diameter of the drivers, a helix having a lead of 40 in. or four times the machine lead is produced. Conversely, if the driven gears are one-half the diameter of the driving gears, a helix with a lead of $2\frac{1}{2}$ in. or one-quarter of the machine lead is produced. Expressing the ratios as fractions,

$$\frac{\text{Driven gears}}{\text{Driving gears}} = \frac{\text{Lead of required helix}}{\text{Lead of machine}}$$

This may be written as

$$\frac{\text{Product of the driven gears}}{\text{Product of the driving gears}} = \frac{\text{Lead of required helix}}{10}$$

Example 3: If a helix having a 12-in. lead is to be cut, the train of gears may be computed as follows, using the formula $\frac{\text{Product of the driven gears}}{\text{Product of the driving gears}} = \frac{\text{Lead of required helix}}{10} = \frac{12}{10}$. Then 12/10 represents the value of the train of gears to be used, which corresponds with x in the simple- and differential-indexing formulas. Reducing the fraction 12/10 to two fractions so that the resulting numerators and denominators will correspond with the number of teeth of four change gears, then

$$\frac{12}{10} = \frac{3}{2} \times \frac{4}{5} = \frac{72}{48} \times \frac{32}{40}$$

The 72- and 32-tooth gears represent the driven gears, and the 48- and 40-tooth gears represent the drivers, i.e., the 72 is the worm gear, 40 is the first gear on stud, 32 is the second gear on stud, and 48 is the screw gear.

The Method of Milling

There are five general methods of milling operations based on the nature and location of the fixtures used.

Simple milling involves the machining of a single piece of work held in a fixture, as illustrated in Fig. 32, and by job-shop clamps, as shown in Fig. 37. This operation can be performed on any type of milling machine. Inasmuch as the machine is idle during the loading operation, this method does not yield the maximum output per machine except where the cutting time is exceedingly large in relation to the loading time, as is the case in many hand-milling operations. Simple holding devices or fixtures are employed.

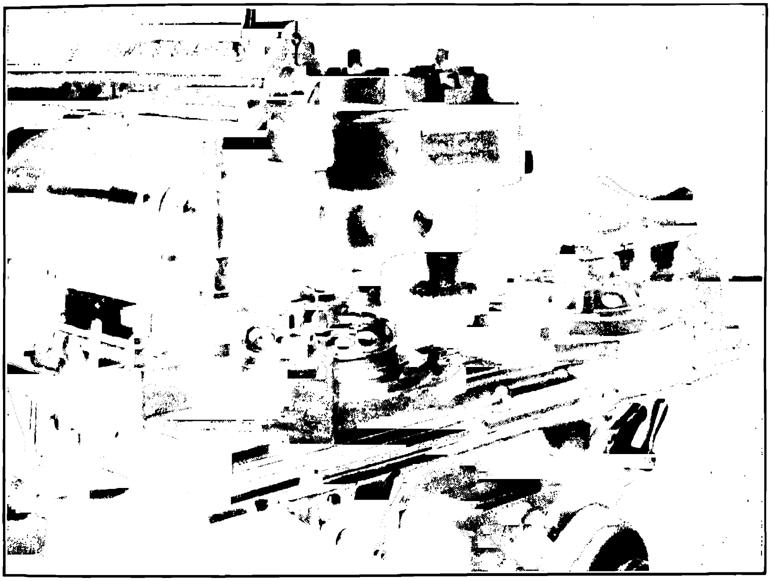
Courtesy Cincinnati Milling Machine Co.

FIG. 32. Form Milling a Cast-Iron Shoe of a Clothes-Pressing Machine on a Cincinnati No. 5-48 Plain Hydromatic Miller with a Plain Fixture.

A 40-in.-radius concave form-milling cutter 15 in. long of high speed steel is used, which has a contact surface of about 15½ in. From $\frac{1}{16}$ to $\frac{3}{16}$ in. of stock is removed from the piece 45 in. long with a feed of 30 in. per min at 50 rpm of the cutter. Production is 20 pieces per hr.

String or **line** milling is a logical development of simple milling. Instead of having but one piece in a fixture on the machine table, two or more are placed in line in multiple fixtures. The fixtures are loaded while the machine is idle. The operator may load one or two pieces and then start the cut, finishing his loading while the cut is progressing. He may have time to remove the first pieces milled before the last ones are finished. Full automatic table control is available on a number of the fixed-bed automatic milling machines. This automaticity simplifies and expedites the operation and relieves the operator of considerable effort. The usual cycle consists of the rapid traverse of the table to the cutter after the fixture is loaded, the engagement of the cutting feed, rapid traverse between pieces if the noncutting space is large, and the rapid return of the table to the starting point after the cut is finished.

Reciprocating milling is a very efficient and productive method on some operations, such as face milling or slotting, as illustrated in Fig. 33. Two fixtures are employed, mounted on each end of the machine table and on opposite sides of the cutter. The operator loads one fixture and starts the machine-table cycle. While the work in this fixture is being machined, the fixture on the other end of the table is reloaded. The most favorable results are obtained when the milling and loading times are properly balanced. The machine should be equipped with a fully automatic table cycle for successful operation, and special precautions must be taken to maintain safe working conditions.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 33. Reciprocating Milling Fixture with a Special Two-Spindle Head Mounted on a No. 21 Brown and Sharpe Automatic Milling Machine.

The opening for the oil ring in the end bracket of a cast-iron motor cage is being milled. As these parts are made in several sizes, the fixtures and cutters are designed so that, without any adjustment of the machine, any part can be milled. A 3½-in.-diam. and ⅝-in.-wide staggered-tooth high speed steel milling cutter operating at 109 rpm mills the parts loaded in the fixture on that end of the table. It has a length of cut of 3½ in., and the cutting time is 34 sec, producing 46 pieces per hr. Parts loaded in the fixture on the other end of the table are milled by a 4½-in.-diam. cutter rotating at 101 rpm. The length of cut is 1⅜ in. with a cutting time of 37 sec per piece. The production of 46 pieces per hr per fixture is based on the assumption that parts are delivered to the machine in quantities and sizes such that the operator can operate both fixtures, reloading one while the other is working. The machine also may be operated by using only one fixture and cutter, in which case 46 pieces per hr are produced. This production may be increased to approximately 60 pieces per hr by interrupting part of the automatic cycle and speeding up by hand.

Index-base milling involves work-holding devices or fixtures which are mounted on an index base carried on the machine table, Fig. 34. The operator, standing at one end of the table, reloads the fixture away from the cutter while the milling is taking place on pieces held in the other fixture. This simplifies the handling of work in and out of the machine. The operator is always a safe distance from the cutter. On a 180-deg index base, which is the one most commonly employed in milling, only two work-holding fixtures are required. Index fixtures can be made to index automatically, although the hand index fixture is most common for the reason that it is simpler in design and automatically provides a safety stop for the operator in case his loading is not finished.

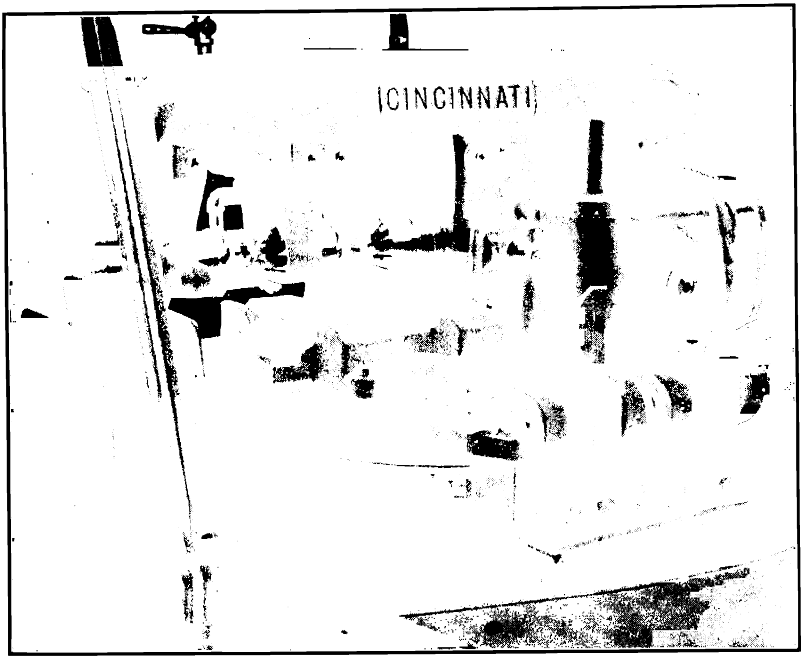


Fig. 34. An Indexing Fixture with Work Arranged in Two Groups Abreast for String Milling on a Cincinnati 5–48 Plain Hydromatic Milling Machine.

Mild steel counterweights are being form milled from solid rectangular shapes. Two sets of two alternating-tooth slotting cutters and two special form radius cutters of high speed steel are operating at 40 rpm and an average feed of 2.5 in. per min. Production is 162 pieces per hr, or 0.33 min each. Extreme rigidity is required for such a wide cut. The operator is reloading the forward end of the fixture while the pieces in the rear portion are being milled. The fixture is then indexed 180 deg and the automatic cycle reproduced.

Rotary milling, which may be applied either horizontally, as illustrated in Fig. 13, or vertically, Fig. 15, gives a high rate of production with the simplest possible cycle for the operator. The cost of fixtures involved in rotary milling is, as a rule, large as compared to reciprocating or index-base milling.

Milling Fixtures

In production milling the equipment should be operated up to its maximum efficiency as near 100 per cent of the time as is possible. The loading and unloading of the fixtures, therefore, should be performed in less time than that required for the actual cutting. Simple and rapid chucking and clamping are, therefore, important in fixture design. Various types of clamping devices, such as simple nuts, handle nuts, cam clamps, wheel-, air-, or oil-operated clamps, are to be used where best adapted. The location of clamping devices is important. Handles, clamps, bolts, pilot wheels, etc., should be within convenient reach of the operator from his normal working position, and they should be as far removed as possible from the cutters. Wherever practicable, clamping levers should operate to clamp more than one piece, thus reducing the number of movements necessary on the part of the operator. A compensating mechanism must be employed in such clamps to provide for variations in the size and shape of the work. It is frequently desirable to provide means for mechanically ejecting the work from the fixtures in order to save the operator's time. Ejecting mechanisms may be made to operate when the clamps are released.

The fixture should support the piece adequately. It should be heavy enough to absorb the strains to which it is subjected. It should be so constructed that the cutting takes place as close to the table and as near the spindle end of the machine or as near an arbor support as possible. Cutters acting high above the table have a tipping and lifting tendency which produces chatter. Chatter or lack of rigidity is extremely detrimental to high feeds and consequently high production. The aim should be always to hold the piece securely enough to operate at the maximum feed which the cutter and machine will stand. The shape of the piece will determine the type and location of the supports. The work should be located and supported as near the point of cutting as possible and place the clamp directly over the point of support to avoid distortion. Clamps, even though acting against the side of a piece of work, should tend to pull the work down on the support. Cutting pressures should act against solid stops or supports and not against clamps.

MILLING CUTTERS

Classification and Definition

Milling cutters are made in a wide variety of sizes and shapes, and they may be classified in a number of ways as follows (see standard on milling cutters, ASA B5, 1949):

A. Milling cutters based on **relief of teeth.**

1. **Profile cutter:** Milling cutter on which the relief is obtained by grinding a narrow land back of the cutting edge; i.e., it is sharpened by grinding the tooth on the periphery of the cutting edges (see Fig. 35).

1. (*a*) **Shaped profile cutter:** Milling cutter made to be sharpened in the same manner as profile cutters, but with cutting edges of irregular or curved shape (see Fig. 32).

2. **Formed cutter:** Milling cutter, the eccentric relief of which has the same contour as the cutting edge. These cutters are sharpened by grinding the *face* of the tooth in its original plane with respect to axis, Fig. 41.

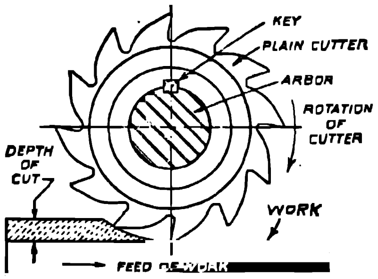


Fig. 35. An End View of a Plain Milling Cutter, Showing Nomenclature and the Out-Cutting Action.

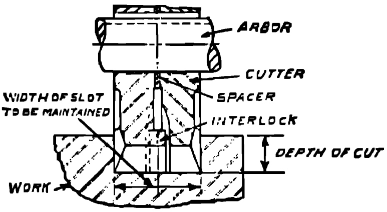


Fig. 36. A Sectional View of Interlocking Side Milling Cutters, Showing How the Width of Slot May Be Controlled by Using Spacers of Various Thicknesses.

B. Milling cutters based on **method of mounting.**

1. **Arbor cutter:** A cutter with hole for mounting on an arbor. The most common types have a straight hole with keyway, Fig. 35. Sometimes the keyway is across one end as in shell end mills, Fig. 39. Cutters also are made with a threaded hole.

2. **Shank cutter:** A cutter having either a straight or taper shank integral with the cutter, Fig. 38. Taper shanks may be driven by the friction between the shanks and spindle for light cuts, with or without the use of a draw-in bolt, or positively by a tang.

3. **Facing cutter:** A cutter designed to be attached directly to the spindle-end or a stub arbor, Fig. 13.

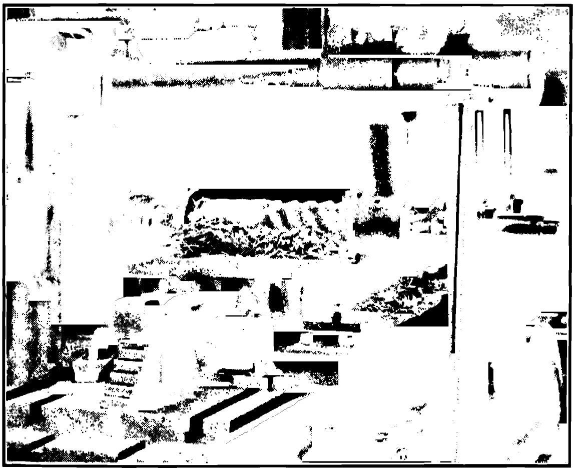
C. Milling cutters may be made from a **solid** piece of cutting material, Fig. 35, or they may consist of a body in which the teeth of the cutting material are **inserted,** Fig. 13.

D. **Hand rotation** of milling cutters.

The **hand of rotation** of any cutter may be determined by looking at the cutter end of spindle. If the cutter rotates counterclockwise, it is right hand; if it rotates clockwise, it is left hand.

E. Definitions of various **types** of milling cutters. (Dimensions also are given in the standard.)

1. **Plain milling cutter** (slabbing mill): Cutter of plain cylindrical form having teeth on the circumferential surface only. Teeth are usually helical for widths above ¾ in. See Fig. 35. A right-hand helix twists away, clockwise, from the observed end.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 37. A Pair of Half-Side and Helical Milling Cutters Set Up for Milling the Two Edges and Face of a Cast-Iron Surface Plate.

Clamping fixtures consist of a variety of miscellaneous parts commonly used in job-shop work.

2. **Side milling cutter** (straddle mill): Cutter of cylindrical form having teeth on the circumferential surface and also on both sides. The side teeth extend a portion of the distance from the circumference toward the axis. See Figs. 36 and 43.

3. **Half-side milling cutter:** Cutter of cylindrical form having teeth on the circumferential surface and teeth on one side only. The side teeth extend a portion of the distance from circumference toward the axis. These cutters are frequently used in pairs for milling both ends of the work to a given dimension. See the end cutters of the gang shown in Fig. 37.

4. **Interlocking side milling cutter:** Similar in design to a side milling cutter except that it is made in a *unit* of two interlocking sections for the purpose of

milling slots to exact width. Maintained at constant width by use of thin shims or collars between inner hubs. See Fig. 36.

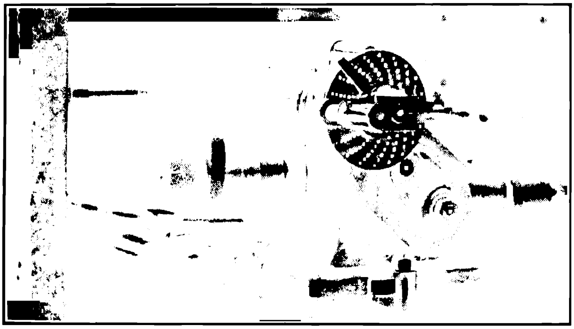
5. **Staggered-tooth milling cutter** (alternate-tooth cutter): Cutter of cylindrical form having *cutting* teeth on the circumferential surface only, the teeth cutting alternately on one side and then on the other, Fig. 40.

6. **Metal-slitting saw:** Plain milling cutter with sides relieved or " dished " to afford side relief, generally made in thickness of 3/16 in. or less, and generally having more teeth for a given diameter than a plain milling cutter. Used for cutting off work, or milling very narrow slots. See Fig. IX-11.

6. (*a*) **Metal-slitting saw** with side teeth: Similar to side milling cutter but 3/16 in. or less in thickness.

(*b*) **Metal-slitting saw** with staggered teeth: Similar to staggered-tooth milling cutter but generally 3/8–3/16 in. thick, used for heavy sawing in steel.

(*c*) **Screw-slotting cutter:** A thin cutter made of sheet stock having comparatively fine teeth on its circumferential surface, and not ground on the sides. Used only for shallow cuts.



Courtesy Barber-Colman Co.

FIG. 38. A Barber-Colman Helical End Mill Set Up in a Kearney and Trecker Milling Machine for Profiling a Cast-Iron Master Cam.

This is a toolroom job. The outline of the cam is accurately scribed on the blank, the blank then mounted on an arbor supported in the spindle of the dividing head which is set at right angles to the table. The feed of the table is synchronized with the rotation of the work to follow the guide lines. End mills are made with right or left helical teeth on the periphery and radial teeth on the end. The radial teeth are slightly undercut and do not extend to the center of the cutter so that an end mill cannot be fed lengthwise into solid stock. A pilot hole must be provided. End mills are used principally when cutting on the periphery. The end mill may have a straight shank to be held in a collet or be provided with a taper shank and tang.

7. **Single angle milling cutter:** Cutter having teeth on the conical surface and with or without teeth on one or both of the flat sides. The *included* angle between the conical face and larger flat face designates the cutter, as for example 45 deg or 60 deg. See Fig. 41.

8. **End mill:** Cutter with teeth on circumferential surface and one end, having integral shank (either straight or taper) for driving. The teeth may be parallel to axis of rotation or helical and either right or left hand. The hand of rotation is determined by viewing end teeth; if counterclockwise, right hand; if clockwise, left hand. End mill with moderate helix angle is commonly referred to as a spiral end mill. See Fig. 38.

8. (*a*) **Two-lip end mill** (slotting mill): A shank cutter with two cutting teeth

on circumferential surface, and end teeth cut to center. Flutes are either straight or helical. Cutter can be sunk directly into material to be milled and then fed longitudinally.

9. **Shell end mill:** A cutter having teeth on circumferential surface and on one end. The tooth end is recessed to receive nut or screwhead for holding cutter on a stub arbor. Generally driven from keyslot across back face. Teeth may be parallel to axis of rotation, or helical, and either right or left hand. See Fig. 39.

10. **T-slot cutter:** A shank (may be either straight or taper) cutter designed for milling T slots having teeth on circumferential surface and both sides. See Fig. 40.

11. **Woodruff key seat cutter:** (*a*) Shank type (may be either straight or taper) cutter having teeth generally on circumferential surface only with sides slightly concaved for clearance.

(*b*) Hole type — the style generally used in sizes larger than 2 in. diam. These cutters are also made with staggered teeth. Both types are used for the specific purpose of milling semicylindrical keyways in shafts for Woodruff keys.

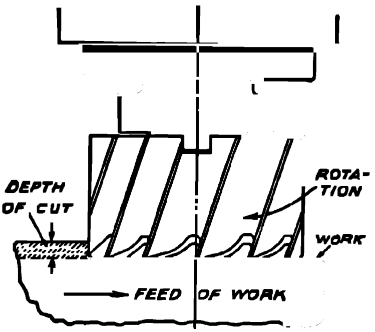
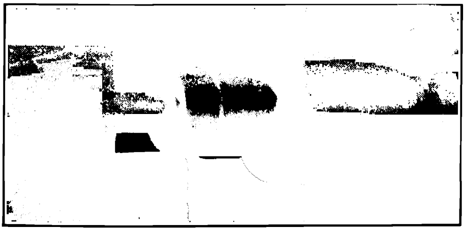


FIG. 39. A Shell End Mill of High Speed Steel for Heavy Work, Showing the Cutting Action of a Typical Setup.

The cutter is held on the end of the arbor by a screw, but is driven positively by the large key.

12. **Hollow mill:** A cutter of tubular construction having teeth on one end and internal relief. The internal relief is sometimes obtained by a plain tapered hole having back taper, and sometimes by internal cleared flutes. Generally used for sizing cylindrical stock or machining straight ends of work.



Courtesy Morse Twist Drill and Machine Co.

FIG. 40. A T-Slot Cutter with Alternate Teeth and Brown and Sharpe Taper Shank and Tang.

The taper shank is fitted into a sleeve which, in turn, fits into an adapter held in the spindle.
A T slot is being cut in cast iron. A slot is first milled with a two-lip mill, after which the undercut is done with a T-slot cutter. Cutting speeds of 100 to 120 surface fpm are recommended in cast iron with a feed of 0.015-0.030 ipr of the 8-staggered-tooth cutter. These speeds and feeds are dependent upon the size of the cutter, being reduced for small cutters and increased for large cutters.

13. **Gear cutter:** Formed cutter for cutting one space at a time in gears, Fig. XIV-6.

13. (*a*) **Multiple gear cutter:** A single unit formed cutter or two or more formed cutters made to mill two or more spaces at one pass in a gear.

(*b*) **Gear roughing cutter** (stocking cutter): Formed cutter for roughing out gears. Frequently the teeth are irregularly nicked to break up the chip. May be single or multiple type or may be used in combination with a finishing cutter.

14. **Sprocket cutter:** Formed cutter for milling one space at a time in sprockets.

14. (*a*) **Multiple sprocket cutter:** A single unit formed cutter or two or more formed cutters made to mill two or more spaces at one pass in a sprocket.

(*b*) **Straddle sprocket cutter:** A formed cutter for finishing one tooth at a time on roller chain sprockets.

15. **Convex cutter:** Formed cutter to mill a concave surface of circular contour equal to a half circle or less. Size is designated by specifying *diameter* of circular form. See Fig. 41.

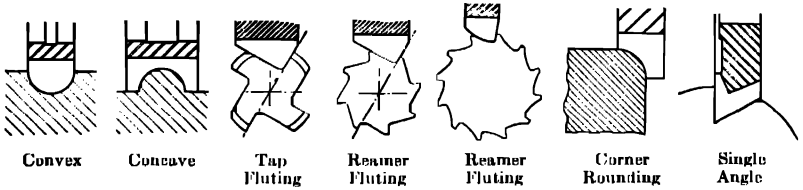


FIG. 41. A Number of Types of Form Cutters.

All cutters are sharpened by grinding only on the face, except the angular cutter which is a profile cutter and is ground on both the face and land. Each of the above cutters is made in various sizes.

16. **Concave cutter:** Formed cutter shaped to mill a convex surface of circular contour equal to a half circle or less. Size is designated by specifying *diameter* of circular form. See Fig. 41.

17. **Corner-rounding cutter:** Formed cutter for milling a circular corner on work up to one-quarter of a circle. May be made single or double. See Fig. 41.

18. **Spline cutter:** These cutters may be of the *single* or the *duplex* type.

The **single** type is a formed cutter for milling a single flute at a time in spline shafts.

The **duplex** type is a formed cutter used in pairs for milling two flutes at one pass in spline shafts.

19. (*a*) **Thread milling cutter:** A single cutter used for milling one thread at a time, generally worm or Acme thread type. These cutters are customarily made 29 deg included angle and may be either profile or formed type. In the profile type, there are two common styles, the first of which has every tooth full and complete; the second, known as the interrupted type, has every other tooth cut away on alternate sides to afford chip clearance with the exception of one tooth which is left full and complete for gaging. See Fig. 16.

(*b*) **Multiple-thread milling cutter:** Generally called threading hob, although *having no lead*. A shank or hole-type formed cutter for milling threads. The length of cutting face is at least one pitch longer than the length of thread to be milled. Both internal and external threads may be milled, also parallel or tapered work. See Fig. 17.

20. **Hob:** Formed milling cutter, the teeth of which lie in a helical path about

the circumferential surface of the cutter. Generally used for spur and helical gears, worm wheels, sprocket teeth, ratchets, spline shafts, etc., Fig. XIV-18.

21. **Inserted-tooth cutter:** Cutter in which teeth are inserted and secured by various methods in a body of less expensive material, the object being economy in first cost and also in maintenance because of opportunity for tooth replacement, see Fig. 13.

21. (*a*) **Inserted-tooth facing cutter:** A cutter adapted to be attached directly to spindle end, or stub arbor, and having inserted teeth cutting on circumferential surface and one end, similar to side mill. See Fig. 13.

22. **Helical mill:** Helical mills are of the profile type. They may be either hole or shank style. Although most slab mills and shank end mills have their peripheral teeth at a slight helix angle, the name "helical mill" is used to designate a high (45 deg or greater) helix angle of tooth, Fig. 53. Used for slab milling, Fig. 48, or for profiling, such as cam milling and for elongating slots. Shank type, with pilot end, is used for elongating slots. See Fig. 37 in which right- and left-hand helical mills are used to eliminate end thrust.

23. **Intermittent-tooth-type cutter:** Formed cutter having a tooth contour of fine points such as a thread milling cutter or hack-saw milling cutter in which succeeding lands around the cutter carry alternately only half the necessary cutting points so staggered as to complete the full required pitch on the finished work. These cutters may be of the shank or arbor type.

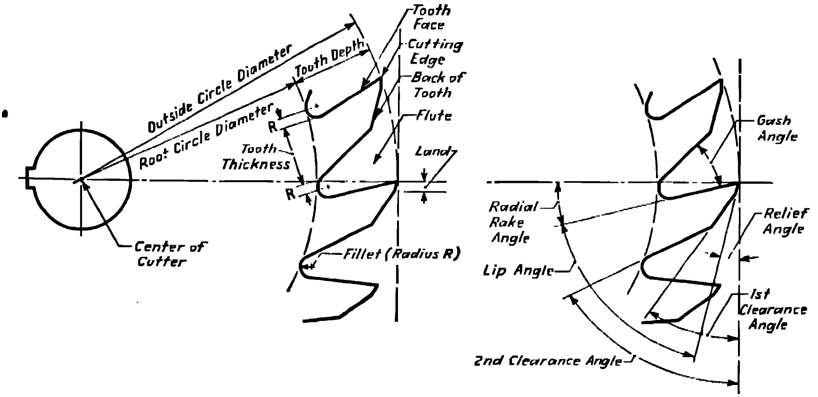


FIG. 42. Nomenclature of Solid Plain-Milling Cutter Teeth (End View), Showing Angles and Parts of Teeth (ASA B5c1, 1947).

Nomenclature of Milling-Cutter Teeth

The geometric form of a plain milling-cutter tooth, as viewed from the end, is shown in Fig. 42. The names of various parts are indicated as the cutting edge, tooth face, land, and back of the tooth. The principal dimensions are the tooth thickness at the base and depth.

The back of the tooth may be formed by a smooth curve extending from the land to the tooth base circle, or it may be made up of one or two straight lines or a straight line and curve. The tooth face may be radial or at an angle called **rake.** The rake permits free cutting, resulting in a better finish on the work, and less power consumed. The space between the back of one tooth and the face of the next constitutes the **chip space.** This space should be large enough to permit resharpenings of the tool and of such a size and shape as to permit the chip to coil freely without clogging.

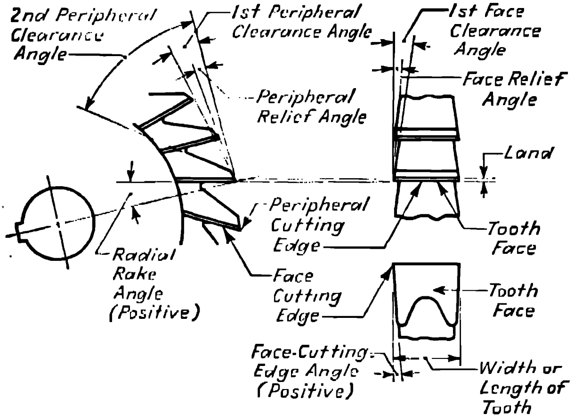


FIG. 43. Nomenclature of Side-Milling Cutter Teeth.

The **cutting edge** or **lip** of the profile cutter is formed by grinding the face or land. The **relief angle** is the angle between the land and the tangent at the lip. The **lip angle** is fixed by the values of rake and **relief** angles.

The nomenclature of the teeth for side-cutting mills and face mills is shown in Figs. 43 and 44.

Number of Teeth in a Cutter

The influence of the number of teeth in a cutter is only indirect. It affects power efficiency only as the thickness of the chip is changed. A thick chip is removed more efficiently than a thin one. Also a tooth will remove more metal per grind by taking thick chips. Milling cutters vary so much in size, shape, and purpose that no general rule can be made. With fewer teeth, the chip space can be made larger so that heavy-duty or roughing cutters are of the coarse-tooth type.

There is no recognized standard practice among cutter manufacturers regarding the number of teeth in a cutter of a given diameter. The National Twist Drill and Tool Co. has for years used the following formula for the number of teeth in all ordinary cutters such as plain and side milling cutters and end mills, for general purposes as well as for the majority of production cutters: $n = 19.5R^{1/2} - 5.8$, in which n is the number of teeth and R the radius in inches of cutter. For a 4-in.-diam. cutter, $n = 19.5 \times 2^{1/2} - 5.8 = 21.8$, or 22 teeth.

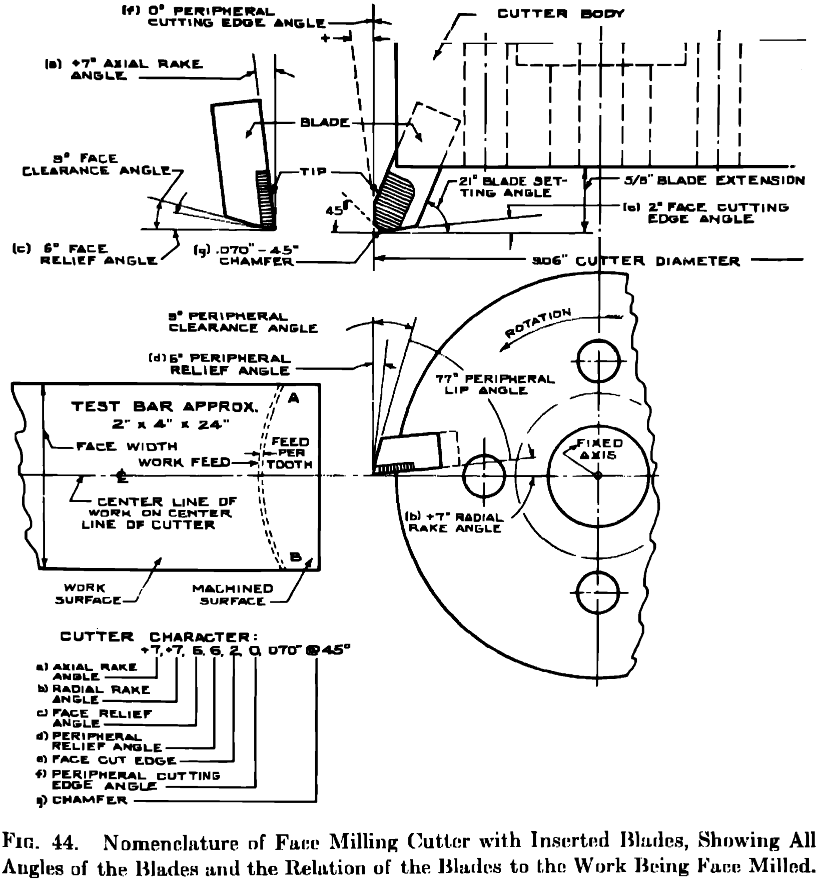


FIG. 44. Nomenclature of Face Milling Cutter with Inserted Blades, Showing All Angles of the Blades and the Relation of the Blades to the Work Being Face Milled.

The blades are tipped with a cast-iron grade of sintered carbide for milling cast iron as shown in Fig. 5.

When taking a deep cut or a long chip with heavy feed, or when facing a large surface, the chip space of the usual cutter may prove inadequate. Also, a considerable number of teeth will be in contact with the work at the same time. If rigidity or available power will not allow each tooth to take the proper thickness of chip at a satisfactory cutting speed, either the thickness of chip or feed must be decreased or the number of chips per minute lessened. The latter is desirable, inasmuch as thick chips are removed more efficiently from a power standpoint and a greater volume of metal is removed per tool grind. For this purpose a cutter having a number of teeth determined from the following formula has been found satisfactory for all cutters 3 in. diam. or larger: $n = 2D + 8$, in which D is the diameter in inches of the cutter. If D is 4 in., then $n = 2 \times 4 + 8 = 16$ teeth. Cutters with inserted carbide teeth often have fewer teeth, such as D or $D + 2$. For face milling cast-iron and nonferrous metals on high-powered mills, the number of teeth may equal $2D$. In face milling the ratio of cutter diameter to width of cut should be about 4.5 to 3, and the cutter should be **offset** so as to start a chip of nearly maximum thickness.

Materials of Which Cutters Are Made

Small milling cutters are made in one piece of carbon tool steel, high speed steel, or Stellite. Small-tool manufacturers can furnish cutters in either carbon or high speed steel cut from bars, hardened and ground. Cutters made from forged high speed steel blanks give greater tool life than those made from blanks cut from rolled bars larger than 4–5 in. diam. The Haynes-Stellite Co. cast Stellite cutters to size and shape so that only finish grinding is necessary. To save Stellite in larger cutters, the Stellite teeth are cast directly about steel bodies or hubs.

The bodies of most cutters larger than 6 in. diam., used in production, are made up of a medium-carbon or alloy steel, and the cutting teeth are made of cutting-tool metal. High speed steel, Stellite and solid carbide bits or blades, or steel blades tipped with sintered carbide are held in slots by wedges or by wedges and screws. By so doing, the teeth may be renewed readily with little cost. All inserted teeth are ground after they have been adjusted in the body, so they are true with respect to the axis of the body. These tool materials and their characteristics have been discussed in Chap. V. The principal dimensions of inserted-blade milling cutters are given in ASA B5.3, 1950.

Definitions of Cutting Speed, Feed, and Depth of Cut

The **cutting speed** of a milling cutter is the peripheral lineal speed resulting from rotation. It is a product of the circumference of the cutter and the number of revolutions per minute, and usually is expressed in feet per minute.

$$V = \frac{\pi D N}{12}$$

in which $\pi = 3.1416$.
V = the cutting speed in feet per minute.
D = the outside diameter of the cutter in inches.
N = the revolutions of the cutter per minute.

The **depth of cut** is usually the distance between the original and final surface, or the thickness of the layer of material being removed. Figure 45 indicates a section of a plain milling cutter in action, with the feed per tooth and depth of cut indicated. Also, see Figs. 35 and 39.

The **feed** in milling may be expressed as

f = feed of the work in inches per tooth of the cutter, or
f' = feed of the work in inches per revolution of the cutter, or
F = feed of the work in inches per minute into the cutter.

If n represents the number of teeth in the cutter, and N represents the revolutions per minute of the cutter, then $F = Nf' = fnN$.

In milling practice the feed per tooth of the milling cutter is the logical basis for computing the speed and feed for any given setup. If the cutter has 12 teeth, and a feed per tooth of 0.005 in. is selected as being appropriate for a given cutting condition, then the machine in which the feeds are expressed in inches per revolution of the spindle would be set up for a feed of 0.060 ipr. The feed per tooth would remain at 0.005 in. regardless of the cutting speed or revolutions per minute of the spindle. In the geared or hydraulic-drive machine where the feed is expressed in inches per minute, if the cutter has 12 teeth and a feed of 0.005 in. per tooth is selected, the feed per revolution of the cutter still would be 0.060 in.; if the cutter rotates at 80 rpm, then the feed or table travel would amount to 4.8 in. per min. If the cutter speed is increased to 100 rpm, the feed in inches per minute remains 4.8, so the feed is reduced to 0.048 ipr, or 0.004 in. per tooth.

It is seen that, in the first case, the feeds could be selected and then the speeds adjusted by trial until satisfactory performance is obtained, with the feed in inches per tooth remaining constant. In the second illustration if, after the table feed in inches per minute is selected, there is a change in cutting speed or revolutions of the cutter, the feed per tooth of the cutter also is changed.

The Formation of a Chip in Milling

In the milling process each tooth of the cutter cuts intermittently, i.e., for only a portion of a complete revolution. **In face milling,** Fig. 44, the length of each chip, A–B, is dependent upon the width of the cut. If the width of the cut equals the diameter of the cutter, then each tooth will cut for a complete half revolution. Usually, however, the width of the face being machined is less than the diameter of the cutter. The thickness of each chip in face milling is greatest immediately ahead of the center of the cutter and is less on either side.

For all cutters which cut on the **periphery** of the tooth, the length of the chip removed by each tooth depends principally upon the depth of cut and cutter diameter. Figure 45 shows an end view of milling cutters cutting on the periphery. The crosshatched area at *A* indicates the sectional area of the chip removed by a single tooth. The feed per tooth and depth of cut are indicated. The tooth comes in contact with the surface of the work at the point *X* and leaves the work at the point *Y*. It rubs over the surface at the point *X* as the material is fed to the right, as indicated by the arrow, while the cutter rotates clockwise, until the force between the tooth and the work is sufficient to cause the cutting edge to dig in. If cutters are dull, a considerable force between the work and cutter is necessary before a chip starts to be formed. The thickness of the chip, at right angles to the path of the cutting edge, is practically zero at the point *X* and reaches a maximum at the point *Y*. The cross-sectional area of the chip removed is equal to the feed per tooth times the depth of cut.

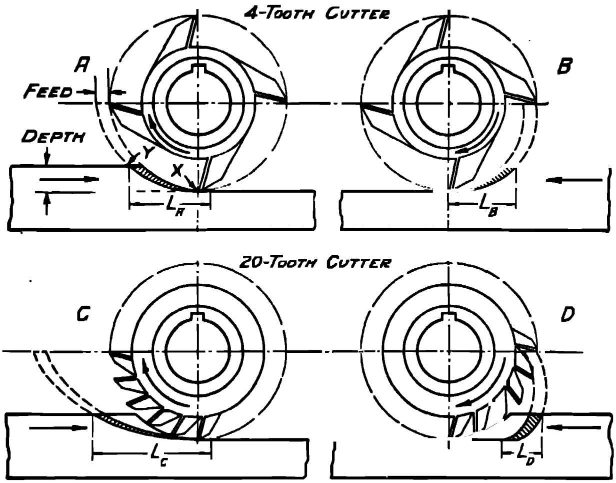


Fig. 45. A Graphical Analysis of Chip Formation When Out-Milling and In-Milling with Coarse- and Fine-Tooth Cutters.

With thick chips removed more efficiently, from a power standpoint, than thin chips, it is seen that the 4-tooth cutter is more efficient when in-cutting at *B* than when out-cutting. It is seen, also, that the fine-tooth cutter is more efficient when in-cutting at *D* than when out-cutting. Further it is seen that the fine-tooth cutter when in-cutting is more efficient than the coarse-tooth cutter when in-cutting, the feed per tooth in all cases being the same.

The cutting condition shown at *A*, Fig. 45, represents that most commonly used. The cutter rotates clockwise while the work is fed to the right, both motions being indicated by arrows. In this manner the cutting tooth cuts against the motion of the work. This is referred to as **out-cutting,** or against the feed, from the machined to the work surface. At *B* the cutter rotates clockwise while the work is fed to the left. This is called **in-cutting** or **climb** or **down**-cutting, in which the cutting action is into the work with the feed. The feed per tooth of the 4-tooth cutter is the same at *A* as at *B*. An analysis of the two chips formed shows that the chip at *A* is thinner and longer than the chip at *B*. Illustrations at *C* and *D* represent, respectively, chips produced by a tooth of a 20-tooth cutter when out-cutting and in-cutting. Again it is seen that the chip at *C* is much longer and much thinner than the chip at *D*. Therefore, the shape of the chip produced by a cutter of a given number of teeth is influenced considerably by the cutting being done, *in* or *out*. The greater the number of teeth in the cutter, the greater the difference in shape of chips.

With the same cutter a less wavy finish usually is obtained when milling *in* than when milling *out*. With proper rigidity of the machine, the cutter, the fixture, and the work, it is claimed that heavier feeds and greater tool life, together with a less burnished and smoother finish on the work, are obtained by in-milling. Chatter is apt to occur when milling out, presumably because of the sliding action of the cutting tooth over the work at the start of the cut. It appears that the built-up edge forms earlier in the cut, and is of a greater size when in-milling. This built-up edge continues to exist to the extreme end of the chip which remains thick in contrast to the chip removed in out-cutting.

SPEEDS AND FEEDS FOR MILLING

In practice, values of cutting speed, feed, and depth of cut vary for different kinds of work and equipment. In the toolroom with its comparatively light machines, makeshift holding devices, and whatever arbor and cutters are available, it is not possible to obtain the high speeds and feeds employed on heavy-production-type machines with carefully constructed fixtures. Values can be set up only as a guide for starting purposes. They then may be modified as experience indicates.

A **cutting speed** should be used which is as high as possible commensurate with satisfactory life of the tool between grinds. High speed and light feed are sometimes necessary in order to produce a very smooth finish. This is always accomplished at the expense of power efficiency. Consistent with the rigidity and strength of the machine, fixtures, and cutters, and with the finish desired, the greatest depth and thickest possible chip per tooth should be taken. After deciding on the heaviest feed per tooth that the cutter can carry without overstraining the cutter or the machine and without overcrowding the chip space or producing an unsatisfactory finish, the cutter speed should then be increased until the point is reached where productivity starts to fall off owing to frequent sharpenings of the cutter. This will lead to efficient and rapid production.

The **correct speed** of the spindle depends upon a number of variables, such as

1. The material, size, type of cutter, and number of teeth.
2. The kind and amount of material to be removed.
3. The relation of depth of cut and feed.
4. The cutting fluid used.
5. The finish desired.
6. The rigidity of the machine, arbor, cutter, fixture, and work.
7. The power available and the strength of the setup.

The **feed** of the work into the cutter is of greater importance than the speed of the cutter, since it governs the output. If the speed is increased, the feed also should be increased to keep the feed per tooth constant. A safe rule to follow is that *the speed should be as fast as the cutter will stand without being ground too often, and the feed as coarse as is consistent with the desired finish, available power, and rigidity.* A combination of speed, feed, and number of teeth should be determined to give maximum metal removal per cutter grind and still leave the desired finish. With carbide tools, the speed is high, so that, to stay within the power capacity of the machine, it is often necessary to reduce the number of teeth in the cutter.

Table 1 is given as a guide to determine the proper speed and feed for high speed steel cutters. Carbon-steel tools should operate at speed from ⅓ to ½ of those of high speed steel tools. Cast nonferrous tools should operate 1.5–2 times and sintered-carbide tools 3–5 times as fast as those of high speed steel. The feeds should be low for hard metals and for small and lightly supported cutters.

Recommended feeds per tooth for different types of cutters when milling various metals are shown in Table 2.

MILLING-CUTTER TEETH ANGLES

Relief angles for plain, side, and face milling cutters of high speed steel are indicated in Figs. 42–44. Specific values are given in Table 1. The relief may be reduced to eliminate chatter or increase tool life on extremely hard metals, as such cutters usually become dull by abra-

TABLE 1. SPEEDS AND FEEDS WITH RAKE AND RELIEF ANGLES RECOMMENDED FOR HIGH SPEED STEEL MILLING CUTTERS OF THE PRODUCTION TYPE OVER 3 IN. DIAM.

A cutting fluid should be used whenever possible. The relief angles should be increased 25–50 per cent for cutters less than 3 in. diam.

Metals	Cutting Speed, fpm	Feed, in. per tooth	Angles, deg	
			Radial Rake	Relief
Aluminum	500–1,000	0.006–0.020	20–40	10–12
Bakelite, plastics	100–200	0.010–0.015	5–10	5–7
Brass	100–200	0.008–0.015	0–10	10–12
Bronze	30–200	0.006–0.012	0–10	4–10
Cast iron	50–120	0.006–0.025	8–10	4–7
Cast iron, malleable	80–100	0.006–0.020	10	5–7
Copper	100–200	0.006–0.015	10–15	8–12
Monel metal	70–80	0.003–0.012	10	5–8
Steel, alloy, heat treated	30–50	0.003–0.015	10–15	4–5
Steel, alloy, not heat treated	60–70	0.005–0.015	10–15	5–6
Steel, annealed high-carbon				
Steel, low-carbon, cold finished	80–100	0.005–0.020	10–20	5–7
Steel, stainless	60–90	0.003–0.012	10	5–8

TABLE 2. FEEDS PER TOOTH FOR DIFFERENT TYPES OF HIGH SPEED STEEL MILLING CUTTERS WHEN CUTTING VARIOUS METALS

(Recommended by the Cincinnati Milling Machine Co.)

Cutter	Feed per Tooth
Saws	0.002–0.003
Slotting cutters	0.003–0.005
End mill	0.001–0.010
Face and shell end mills	0.007–0.025
Spiral mill (helix angles to 30 deg)	0.005–0.010
Helical cutters (from 30 to 60 deg)	0.004–0.008
Form cutters	0.003–0.008

sion on the tooth flank. For general work radial **rake angles** of 10–15 deg are satisfactory. **Axial** or side rakes on side cutters should be used when possible by alternating or staggering the teeth. Helical teeth increase tool strength and permit a smoother cutting action through longer contact of each tooth with the work and its overlapping with the next tooth. Roughing cutters often have nicked teeth or irregular edges to break up the heavy, long chips, Fig. 53. Stellite cutters should have slightly smaller rake angles to make use of the harder metal on the periphery of the blade in forming the face.

The Ingersoll Milling Machine Co. has developed a face mill known as the Shear Clear cutter which, for cutting steel with high speed steel cutters, has an axial rake angle of approximately 30 deg and a negative radial rake angle of 10 deg which, accompanied by a peripheral cutting-edge angle of approximately 40 deg, cause the chips to be coiled in the flutes and thrown to the outside of the cutter, thereby preventing their destroying the finish on the work and binding on the inside of the cutter face.

For **sintered-carbide tools** the **relief** angles may be as small as 3–5 deg for hard metals but 8–12 deg for soft metals and cast iron. **Rakes of sintered-carbide tools** for cutting materials giving discontinuous chips for brass and cast iron (also the light metals) are found to give the highest speed-tool-life constant for positive values of 3–8 deg, while steel performs best with negative rakes of 5–10 deg. The high values are for the harder steels. The Kearney and Trecker face mill with solid blades of sintered carbide ground with a ridge back of the cutting edge at negative 5–9-deg rake with a width of 1½ times the feed, backed by a positive rake of 15–30 deg, provides a lip angle greater than 90 deg to accommodate the carbide of high compressive strength but low ductility, and yet allows the chip to flow freely over the built-up edge supported on the ridge. Negative rake angles are definitely beneficial for intermittent cuts to prevent chipping of the cutting edge. At the start of each cut the impact of the work falls on the face of the carbide tool back of the cutting edge rather than on the cutting edge itself.

Sintered-carbide tools must be operated at **speeds** three to five times those used for high-speed tools, to avoid the chipping of the cutting edge. At speeds below 200–250 fpm chipping is probable, and the tool life will be less than at higher speeds of 300–600 fpm. All blades for cutting steel should be honed to 0.004-in. width on the cutting edge to dull or chamfer it with a 400-grit diamond hone to increase tool life. **Cutting fluids** are used on carbide tools only when a large supply can be directed continuously on the cutting tool. For intermittent cuts in turning or in milling, cutting fluids are deleterious and reduce tool life. The intermittent cooling causes frequent wide temperature changes, and the carbide will develop cracks (heat checks) at right angles to the cutting edge. These cracks will lead to chipping. Light feeds of less than 0.003 in. per tooth cause chipping, and feeds of 0.005–0.012 in. or more are more satisfactory.

A large positive peripheral cutting-edge angle up to 30–60 deg, a wide

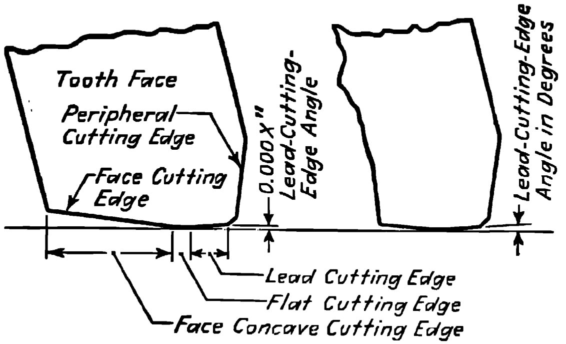


FIG. 46. A Milling Cutter Tooth Face, Showing How the Face-Cutting Edge Is Made Up of a Lead Cutting Edge, a Flat, and a Concave Cutting Edge (ASA B5c1, 1947).

The drawing shows how the lead angle may be designated in thousandths of an inch at the left and by degrees at the right.

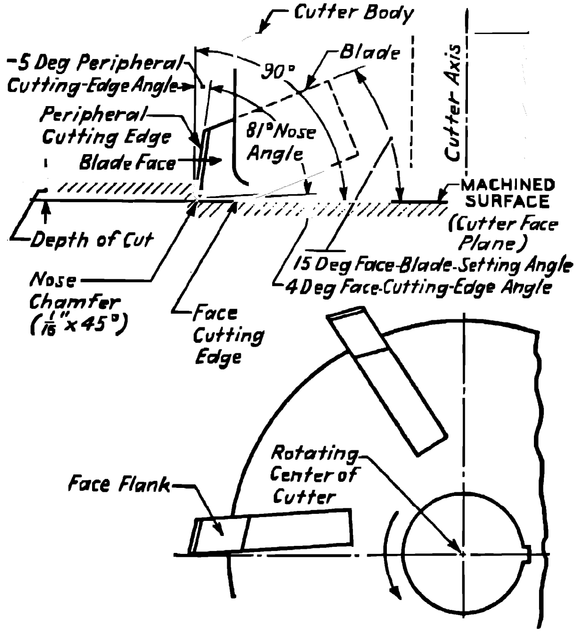

Cutter Body
-5 Deg Peripheral Cutting-Edge Angle
90°
Blade
Cutter Axis
Peripheral Cutting Edge
81° Nose Angle
Blade Face
MACHINED SURFACE (Cutter Face Plane)
Depth of Cut
15 Deg Face-Blade-Setting Angle
4 Deg Face-Cutting-Edge Angle
Nose Chamfer ($\frac{1}{16}$" x 45°)
Face Cutting Edge
Rotating Center of Cutter
Face Flank

FIG. 47. A Typical Face Mill with Blade Placed in Holder to Permit Radial Adjustment Required by Peripheral Wear as for Deep Cuts.

The values shown are for explanatory purposes only.

chamfer, and a nose radius up to ⅛ in. increase the tool life of face mills appreciably. For better work finish, a small face-cutting-edge angle should be used, 1½–2 deg for long life, and ½–1 deg for the better finish. A flat 1/16–⅛ in. will improve the work finish still more, and a flat with a lead angle of about ½–1 deg will reduce chatter for finishing cuts as shown in Fig. 46. It is also good practice to have one tooth with a flat the width of which is slightly more than the feed of the cuts per revolution, with the balance of the teeth having ½-2-deg face-cutting-edge angle for long life.

The face-milling blades may be **held in the cutter body** by wedges, clamps, serrations, and screws. Figure 47 illustrates how the blade is held with a small face-blade-setting angle to permit radial adjustment of the blade when it is reground. This is required when deep cuts are taken, as the wear is principally on the periphery. The blade of Fig. 46 is set nearly axially to permit axial adjustment at the time of grinding to compensate for excessive wear on the face as caused by finishing cuts.

TABLE 3. CUTTING-SPEED TOOL-LIFE EQUATIONS FOR FACE MILLING WITH CARBIDES

Material Cut	SAE 4130 Steel	SAE 4130 Steel	SAE 4130 Steel	SAE 1020 Steel	Cast Iron 40,000 psi
Bhn.	160-170	160-170	400	160	190
Width	$3\frac{3}{16}$	$3\frac{3}{16}$	$3\frac{1}{4}$	$3\frac{1}{4}$	4
Depth of cut	0.188	0.015	0.188	0.187	0.100
Feed, ipt	0.015	0.003	0.015	0.015	0.010
Milling cutter					
Carbide grade	Various	Various	K3H	K3H	K2S
No. teeth	1	1	1	1	1
Diameter	$10\frac{1}{4}$	$10\frac{1}{4}$	$10\frac{1}{4}$	$10\frac{1}{4}$	9
Tooth shape	-10, -10, 3, 3, 2, 45 × $\frac{1}{4}$	-10, -10, 3, 3, 2, 45 × $\frac{1}{4}$	-5, -10, 3, 3, 2, 45 × $\frac{1}{4}$	0, 0, 3, 3, 2, 45 × $\frac{1}{4}$	+7, +4, 6, 6, 6, 2, 0, $\frac{1}{8}$ rad.
Tool-life equation	$VT^{0.35} = 2{,}350$	$VT^{0.45} = 4{,}000$	$VT^{0.45} = 1{,}500$	$VT^{0.32} = 3{,}400$	$VT^{0.37} = 2{,}215$
V_{60}	570	640	260	900	487

Typical cutting-speed tool-life equations when face milling SAE 1020 steel, Meehanite cast iron, and SAE 4130 steel under specific conditions are given in Table 3. The exponent of the actual machining time, T_M, is much greater than that for turning with sintered-carbide tools. When milling a 4-in.-wide face, the actual time of cut, T_A, to produce the 0.030-in. flank wear is $0.14T_B$.

Speeds for sintered-carbide milling cutters for various metals may be as follows for a starting point — lowered or increased as test runs indicate:

Aluminum and magnesium alloys	7,000 fpm
Plastics and nonmetallic metals	1,000
Brass and bronzes	1,000
Cast iron, soft	350
Cast iron, hard	200
Soft steel (110 Bhn)	700
Cold-finished free-cutting steel (160 Bhn)	600
Low-carbon steel (180 Bhn)	550
Steel (200 Bhn)	500
Steel (250 Bhn)	450
Steel (360 Bhn)	300
Steel (400 Bhn)	260
Stainless steel	350

POWER AND ENERGY REQUIRED IN MILLING

Pendulum Dynamometer Tests

At the left in Fig. 48 is shown on log-log paper the net milling energy in foot-pounds per chip for various values of the feed per tooth for three depths of cut, namely, 0.050, 0.100, and 0.150 in., when cutting annealed low-leaded brass consisting of 65.5 per cent copper, 34.1 per cent zinc, 0.25 per cent lead, and 0.10 per cent iron. Lard oil was applied as a cutting fluid. The solid lines represent the energy values when out-cutting, and the dashed lines the values when in-cutting. It is interesting to note that all six lines are parallel, the tangent of the angle of the slope being 0.77. It is seen that, if the depth for a given feed is doubled or tripled, the energy increases almost but not quite in the same proportion. The variable-feed curves show that in-cutting requires less energy than out-cutting, although this relation does not hold true for all metals.

At the right in Fig. 48 are shown the milling-energy values in foot-pounds per chip for variable depths for each of two values of feed per tooth. Again, four straight lines are obtained, all of which are parallel. It is seen that, for a given depth of cut, if the feed is doubled from 0.005 to 0.010 in. per tooth, the energy increase is in the proportion of 2 to 3.5. This shows that thick chips require less energy in proportion than thin chips. The tangent of the angle of slope of these lines is 0.96.

The cutter used in the above tests was a plain mill (an end-cutting tooth), 3.5 in. diam., 0.347 in. wide, having a back-rake angle of 15 deg.

From the results of Fig. 48, an equation giving the relation between the net energy in foot-pounds per chip E, the width of the cutter w, the feed per tooth f, and the depth of cut d, all expressed in inches, may be written as follows: $E = Cwf^{0.77}d^{0.96}$. C represents a constant which when out-cutting is 6,040 and when in-cutting is 5,171, as shown in Table 4. The energy values have been found to vary directly with the width of the cutter, w. The above equation shows that the energy

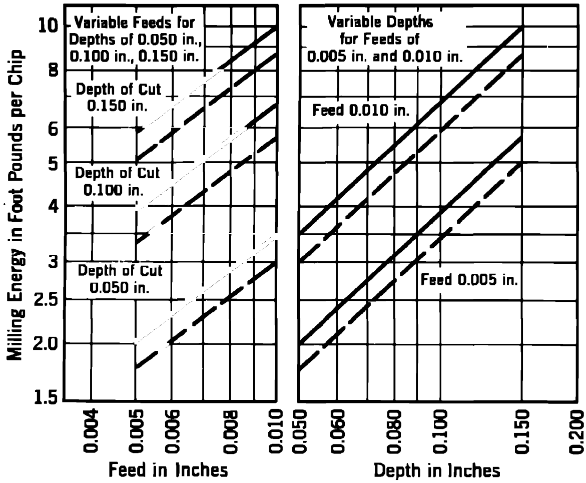


FIG. 48. The Energy at the Tool Point Required in Foot-Pounds per Chip for Various Feeds and Depths of Cut When Milling Brass with a Side-Milling Cutter 0.347 in. Wide When Out-Milling (Solid Line) and When In-Milling (Dashed Line).

per chip increases with an increase in feed and depth of cut only as the 0.77 power of the feed and the 0.96 power of the depth of cut. This proves the desirability, from a power standpoint, of taking heavy feeds.

The total net horsepower developed by the cutter is $hp_c = EnN/33{,}000$, in which n is the number of teeth and N the revolutions per minute of the cutter. This, divided by the cubic inches of metal cut per minute, $wfdnN$, gives the unit hp_c. Net energy and hp_c formulas with values of unit hp_c and constant C for milling different materials both *out* and *in*, with a variety of cutting fluids, are given in Table 4.

Values of hp_c when cutting dry with the same cutter under the same cutting conditions are also given in Fig. VII-22, along with corresponding values for drilling and planing. It is seen that the horsepower per cubic inch per minute when milling varies from about 0.28 for Dow-

TABLE 4. NET ENERGY AND HORSEPOWER FORMULAS WITH VALUES OF THE CONSTANT C FOR MILLING DIFFERENT MATERIALS BOTH OUT- AND IN-CUTTING, WITH VARIOUS CUTTING FLUIDS

(Formula: $E = Cwf^xd^y$, in which C = constant for cutter, material, and cutting fluid; E = energy in foot-pounds per chip at the tool point; w = width of cutter in inches having 15-deg rake; f = feed in inches per tooth, and d = depth of cut in inches.)

Material Cut	Formulas		Unit hp_c*		Values of C		
	Energy, ft-lb per Chip	Unit hp_c	Out	In	Oil No.†	Out	In
SAE 1020 steel	$Cwf^{0.64}d^{0.78}$ both out and in	$\frac{C}{33,000f^{0.36}d^{0.22}}$	1.388	1.160	1	5,520	4,650
			1.084	0.952	4	4,320	3,790
			1.000	0.796	5	3,980	3,170
			1.084	1.043	6	4,320	4,150
			1.043	0.980	8	4,150	3,900
			0.930	0.854	10	3,700	3,400
SAE 3150 steel	$Cwf^{0.70}d^{1.00}$	$\frac{C}{33,000f^{0.30}}$	1.327	1.278	1	11,000	10,600
			1.180	1.082	10	9,780	8,980
SAE 6140 steel	$Cwf^{0.72}d^{0.90}$	$\frac{C}{33,000f^{0.28}d^{0.10}}$	1.44	1.52	1	10,630	11,220
			1.348	1.427	8	9,950	10,520
Free-cutting screw-stock steel	$Cwf^{0.77}d^{0.86}$	$\frac{C}{33,000f^{0.23}d^{0.14}}$	0.954	0.784	6	8,180	6,720
High speed steel	$Cwf^{0.73}d^{0.84}$	$\frac{C}{33,000f^{0.27}d^{0.16}}$	1.437	1.525	1	9,700	10,400
			1.437	1.525	8	9,700	10,400
Cast iron	$Cwf^{0.41}d^{0.56}$	$\frac{C}{33,000f^{0.59}d^{0.44}}$	0.685	0.740	1	595	643
Leaded screwstock brass	$Cwf^{0.76}d^{0.96}$	$\frac{C}{33,000f^{0.24}d^{0.04}}$	0.381	0.358	5	3,830	3,600
			0.381	0.358	6	3,830	3,600
Annealed unleaded brass	$Cwf^{0.77}d^{0.96}$	$\frac{C}{33,000f^{0.23}d^{0.04}}$	0.573	0.491	5	6,040	5,170
Pure copper	$Cwf^{0.62}d^{0.92}$	$\frac{C}{33,000f^{0.38}d^{0.08}}$	1.233	1.049	1	5,980	5,090
			0.795	0.695	8	3,860	3,375
Bakelite	(Out) $Cwf^{0.21}d^{0.75}$	$\frac{C}{33,000f^{0.79}d^{0.25}}$ (Out)	0.143	....	1	74	....
	(In) $Cwf^{0.29}d^{0.83}$	$\frac{C}{33,000f^{0.71}d^{0.17}}$ (In)	....	0.148	1	....	130

* Feed in inches, 0.010; depth of cut in inches, 0.125.

† Cutting fluid 1 is dry cutting.

Cutting fluid 4 is a soluble oil, 1 part oil to 10 parts water.

Cutting fluid 5 is a No. 2 lard oil.

Cutting fluid 6 is a light mineral oil.

Cutting fluid 8 is a light mineral oil containing 10 per cent No. 1 lard oil.

Cutting fluid 10 is a sulphurized light mineral oil.

metal to a maximum of 2.8 for 13 per cent chromium iron. Wherever gross values are given, the efficiency of the machine under load conditions must be taken into consideration in order to arrive at the net power consumed by the cutter.

Dynamometer and Wattmeter Tests

A dynamometer and wattmeter were used on a Cincinnati, No. 4, knee-type milling machine when slab milling annealed SAE 3150 steel. The gross power, tare, and net horsepower were recorded on the wattmeter, while the three components of the force on the cutter were read on the dynamometer. For various values of feed and depth the forces are shown as follows: the horizontal tangential forces, F_T, Fig. 49; axial forces, F_A, Fig. 50; normal or vertical forces, F_N, Fig. 51, for the helical mill described in Fig. 49. Values of net horsepower ($hp_g - hp_t$) for the various values of feed and depth of cut for this 15-deg-rake helical mill are shown in Fig. 52. Equations for these forces for net power and unit net power with specific values of unit net power are summarized in Table 5. (*Trans. ASME*, October, 1937). The gross power developed in out-cutting with a roughing helical mill is illustrated in Fig. 53.

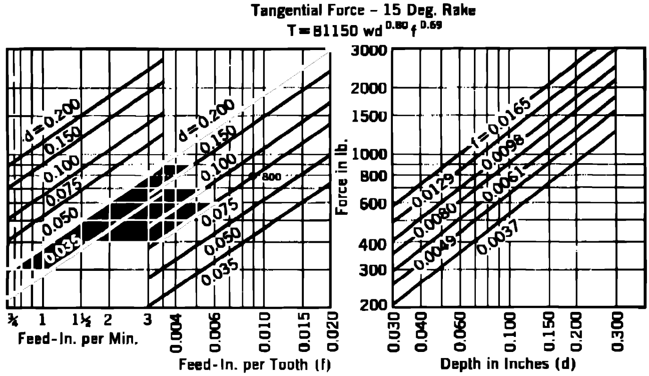


FIG. 49. Tangential Forces Plotted on Log-Log Paper for the 15-deg Rake, 25-deg Left-Hand Helix Slab Mill 3 in. diam., Having 12 Teeth Operating at 17 rpm (13.3 fpm) When Cutting Annealed SAE 3150 Steel at Various Feeds and Depths with a Sulphurized Mineral-Lard Oil, Width of Cut 2 in.

Illustrative problem: Find the tangential force on the milling cutter 3 in. diam. having 12 teeth, 20-deg rake angle, and 25-deg helix angle, operating at 17 rpm, when taking a cut in the annealed SAE 3150 steel 2 in. wide, 0.075 in. deep, and 0.0098 in. per tooth feed. The logarithmic form of the equation, as taken from

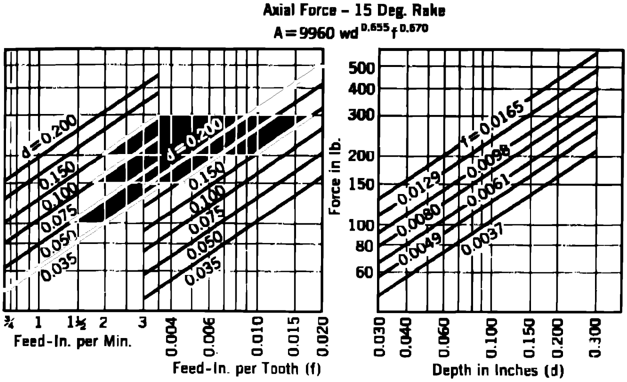


FIG. 50. Axial Forces Plotted on Log-Log Paper for the Cuts Described in Fig. 49.

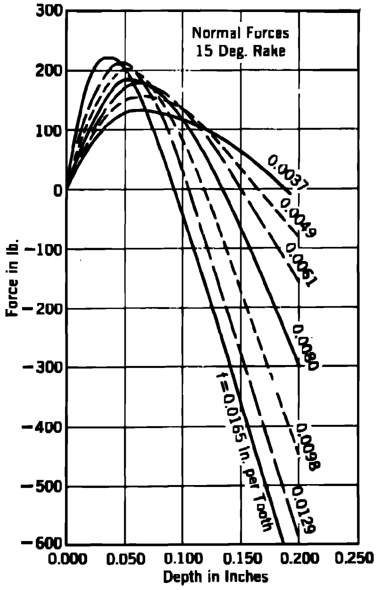


FIG. 51. Normal Forces Plotted on Cartesian Coordinates over the Depth of Cut in Inches for the Cuts Described in Fig. 49.

Table 5, is log $T = \log 72{,}600 + \log 2 + 0.77 \ (\log 0.075) + \ 0.688 \ (\log 0.0098)$. From the logarithmic table, the mantissa of 72,600 is 0.86101, but as the number

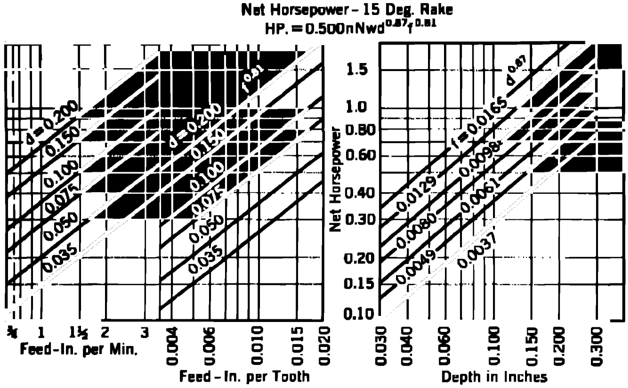
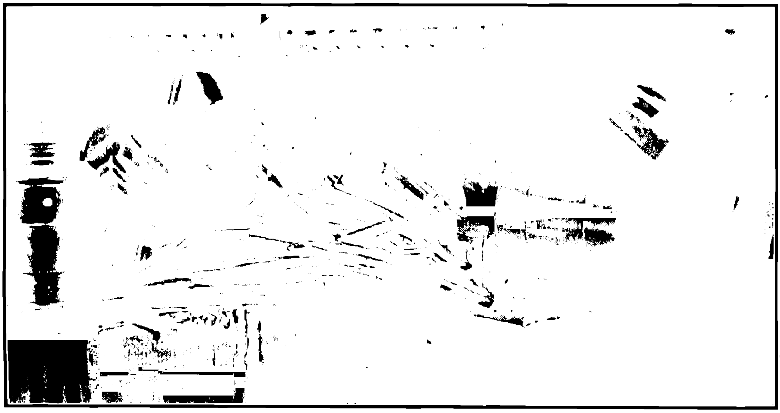


FIG. 52. Net Horsepower as Determined from the Wattmeter for Various Feeds and Depths Plotted on Log-Log Paper for the Cuts Described in Fig. 49.

n = number of teeth in the cutter.
N = speed, rpm.
w = width of cut, in.
d = depth of cut, in.
f = feed per tooth, in.



Courtesy Ingersoll Milling Machine Co.

FIG. 53. Slabbing the Edges of Two Locomotive Drive Rods of 0.40-0.60 Per Cent Carbon Steel on an Ingersoll 100-hp Horizontal-Spindle, Inclined-Rail, Planer-Type Milling Machine.

An Ingersoll 9-in.-diam., helical, plain cutter containing fourteen high speed steel-inserted blades is cutting at 25 rpm or 58.75 fpm, a depth of cut of 2½ in., and a width of cut of 6 in. The feed per minute is 3¼ in., and 53 hp is developed by the motor. A heavy flow of an emulsion is used.

has five digits, the log has a characteristic of 4, resulting in 4.86101. Also 0.77 $(\log 0.075) = 0.77\ (-2.87506) = 0.77\ (8.87506 - 10) = 6.83380 - 7.7$ and 0.688

TABLE 5. FORCE AND POWER WHEN MILLING AN ANNEALED SAE 3150 STEEL WITH FIVE HELICAL MILLS

Cutter Description Left Helix Slab Mill of h.s.s.	Axial Force, F_A (side thrust)	Tangential Force, F_T	hp_c	Unit hp_c*
1. 3″ diam. × 3″ long 12 teeth 25-deg helix **20-deg rake**	$8{,}820wd^{0.683}f^{0.65}$ 140†	$72{,}600wd^{0.77}f^{0.688}$ 770	$0.469nNwd^{0.825}f^{0.825}$	$\dfrac{0.469}{d^{0.175}f^{0.175}}$ 1.70
2. 3″ diam. × 3″ long 12 teeth 25-deg helix **15-deg rake**	$9{,}960wd^{0.665}f^{0.67}$ 155	$81{,}150wd^{0.80}f^{0.690}$ 800	$0.500nNwd^{0.87}f^{0.81}$	$\dfrac{0.500}{d^{0.130}f^{0.190}}$ 1.715
3. 3″ diam. × 3″ long 12 teeth 25-deg helix **10-deg rake**	$10{,}960wd^{0.633}f^{0.695}$ 164	$95{,}350wd^{0.83}f^{0.695}$ 840	$0.522nNwd^{0.914}f^{0.80}$	$\dfrac{0.552}{d^{0.086}f^{0.200}}$ 1.77
4. 3″ diam. × 3″ long 12 teeth 25-deg helix **5-deg rake**	$11{,}900wd^{0.605}f^{0.725}$ 162	$107{,}000wd^{0.87}f^{0.665}$ 910	$0.591nNwd^{0.958}f^{0.784}$	$\dfrac{0.591}{d^{0.042}f^{0.216}}$ 1.81
5. 3″ diam. × 2½″ long 8 teeth 45-deg helix **15-deg rake**	$23{,}500wd^{0.840}f^{0.70}$ 195	$77{,}700wd^{0.920}f^{0.715}$ 495	$0.74\ nNwd^{0.916}f^{0.88}$	$\dfrac{0.74}{d^{0.084}f^{0.120}}$ 1.62

* Value for $d = 0.075$ in., $f = 0.009$ in. per tooth, and $w = 2$ in. See Fig. 49.

† Net hp equals the gross wattmeter power less the tare for machine running idly.

(log 0.0098) = 0.688 (−3.99123) = 0.688 (7.99123 − 10) = 5.49795 − 6.88. Then log T = 4.86101 + 0.30103 + 6.83380 − 7.7 + 5.49795 − 6.88 = 2.91379. The number whose mantissa is 0.91379 is 82, but the characteristic 2 indicates three digits, so T = 820 lb.

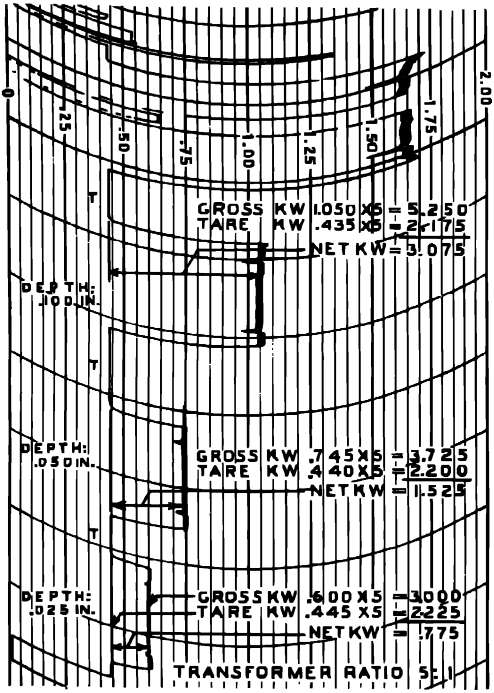


FIG. 54. A Recording Wattmeter Chart.

A cast iron of 17,000 psi and 170 Brinell hardness, 2 in. thick by 4 in. face and 30 in. long, was being face milled on a Kearney and Trecker Corp. 5 HM plain, horizontal milling machine. A face mill 9 in. in diam. with 16 inserted teeth tipped with K2S sintered carbide was operating at 122 rpm or 289 fpm with a feed per tooth of 0.0093 in. for each of several depths of cut. The tooth angles were +7, +4, 6, 6, 2 and 0 deg, 0.070 in. chamfer 45 deg from the cutter face plane. The chart shows how the net power is obtained from the gross and tare.

Wattmeter Power for Face Milling

The 5 HM plain, horizontal, knee-type milling machine shown in Fig. 5 is equipped with a recording wattmeter so that the power delivered to the 20-hp motor in the base which drives the spindle can be recorded. The net power, hp_n, developed by the motor to do the cutting is obtained by subtracting the tare power, hp_t, required to run the machine with speed and feed gears engaged, but not cutting, from the gross power, hp_g, required to drive the machine while the cutting is in process. Such a chart is shown in Fig. 54 in which successive cuts are taken under otherwise constant conditions at depths of 0.025 in., 0.050 in., and 0.100 in. For example, for the depth of 0.100 in. the gross kw is 5.250, the tare is 2.175, giving a net power of 3.075.

Many tests, involving a wide variety of variables of the cutter, the material cut, the cutting fluid, and the cutting conditions of speed and feed, have been run. Table 6 shows the results of power determinations at each of four depths of cut from $\frac{1}{16}$ to $\frac{1}{2}$ in. with four speeds of 100–800 rpm for each depth and at four different feeds ranging from 0.0025 in. to 0.020 in. for each of the above conditions. A cast iron, having a tensile strength of 45,000 psi and a Brinell hardness of 217, was face milled on a 4-in. width of face with a carbide-tipped milling cutter described in the table. From a preliminary study the mechanical efficiency of the machine was found to be approximately 80 per cent, so that

$$hp_c = (hp_g - hp_t) \text{ eff} = 0.80\ hp_n$$

The unit hp_c obtained by dividing hp_c by the cubic inches of metal removed per minute is found to be 0.87 for the $\frac{1}{16}$-in. depth of cut and 0.0025-in. feed for all four speeds. This shows that the unit hp_c is independent of cutting speed. For the 0.005-in. feed and the $\frac{1}{16}$-in. depth of cut the unit hp_c is 0.74. It is 0.64 for the feed of 0.010 in. and 0.55 for the feed of 0.20 in. This shows that for a given depth the unit hp_c is reduced for the larger values of feed. The lowest unit hp_c is 0.43 for the greatest depth and feed. Values of tare for the different speeds are shown above the table.

Sample problem: A typical problem is illustrated here to show how these tables can be used to compute the power requirements for any face-milling cutter when milling the above types of cast iron.

Problem: Compute the horsepower, hp_c, and the gross motor horsepower, hp_g, when face milling a 5-in.-wide (w) bar of cast iron of 217 Bhn and 45,000 psi, Table 6, with a 9-in.-diam. (D), 16-tooth (n) cutter with teeth tipped with sintered carbide as described in Table 6. It is operating at 300 fpm (V), a feed (f) of 0.020 ipt, and a depth of cut (d) of $\frac{3}{16}$-in. The axial and radial rake angles should be equal to or nearly equal to those used in the tests. Less rake will require slightly more power and more rake will require slightly less power.

Solution:

$$V = \frac{\pi DN}{12}$$

from which

$$N = \frac{12V}{\pi D} = \frac{12 \times 300}{\pi \times 9} = 127$$

Feed of work, in. per min = $F = fnN = 0.020 \times 16 \times 127 = 40.64$.

Cubic inches per minute = $dwF = \frac{3}{16} \times 5 \times 40.64 = 38$.

hp_c = unit hp_c × cu in. per min = hp_c/cu in. per min × cu in. per min.

TABLE 6. POWER FOR FACE MILLING A *45,000 Psi Cast Iron* OF 217 BHN 4.0-IN. BAR FACE WIDTH WITH A 9-IN. DIAM., *16-Tooth Carbide-Tipped* (K2S) MILLING CUTTER WITH TOOL ANGLES OF +7, +4, 6, 6, 2, 0 AND 0.070 IN. AT 45° CHAMFER

rpm	hp_t
25	2.07
50	2.13
100	2.23
200	2.43
400	2.93
800	4.42

hp_c per 1.0-in. bar width = $2.61wf^{0.78}d^{0.98}N$

All values given below are for a 1.00-in. bar width and for the 16-tooth cutter.

w = bar width, 4 in.
f = feed, ipt.
d = depth of cut, in.
N = cutting speed, rpm
n = number of teeth

Depth of cut, inch	rpm	hp_c	hp_g	Unit hp_c	hp_c	hp_g	Unit hp_c	hp_c	hp_g	Unit hp_c	hp_c	hp_g	Unit hp_c
1/16	100	0.22	2.51	0.87	0.37	2.70	0.74	0.64	3.03	0.64	1.10	3.61	0.55
	200	0.44	2.98	0.87	0.74	3.36	0.74	1.28	4.04	0.64	2.19	5.19	0.55
	400	0.87	4.03	0.87	1.48	4.79	0.74	2.55	6.14	0.64	4.38	8.44	0.55
	800	1.75	6.62	0.87	2.96	8.14	0.74	5.09	10.82	0.64	8.77	15.47	0.55
1/8	100	0.40	2.73	0.80	0.68	3.08	0.68	1.16	3.69	0.58	2.00	4.75	0.50
	200	0.80	3.43	0.80	1.36	4.13	0.68	2.32	5.36	0.58	4.01	7.47	0.50
	400	1.60	4.94	0.80	2.71	6.34	0.68	4.65	8.78	0.58	8.02	13.03	0.50
	800	3.19	8.43	0.80	5.42	11.24	0.68	9.30	16.12	0.58	16.04	24.62	0.50
1/4	100	0.74	3.16	0.74	1.25	3.80	0.62	2.14	4.93	0.54	3.69	6.88	0.46
	200	1.47	4.28	0.74	2.50	5.57	0.62	4.28	7.81	0.54	7.38	11.72	0.46
	400	2.94	6.63	0.74	4.99	9.21	0.62	8.58	13.73	0.54	14.77	21.53	0.46
	800	5.88	11.82	0.74	9.99	16.98	0.62	17.16	26.02	0.54	29.53	41.62	0.46
1/2	100	1.36	3.94	0.68	2.31	5.26	0.58	3.96	7.22	0.50	6.83	10.83	0.43
	200	2.72	5.85	0.68	4.62	8.49	0.58	7.93	12.43	0.50	13.67	19.63	0.43
	400	5.44	9.77	0.68	9.24	15.05	0.58	15.86	22.93	0.50	27.35	37.33	0.43
	800	10.88	18.10	0.68	18.45	28.66	0.58	31.70	44.42	0.50	54.7	73.22	0.43
			0.0025			0.005			0.010			0.020	
		Feed, inches per tooth											

$$hp_g = \text{Gross horsepower to motor} = \frac{hp_c}{\text{Mech. eff.}} + hp(\text{Tare})$$

hp_c = Net power at cutter or spindle = unit $hp_c \times wfdnN$

Mech. eff. = 79.4 per cent

From Table 6 for $N = 127$, $d = \frac{1}{8}$–$\frac{1}{4}$, and $f = 0.020$ ipt, the unit hp_c is between 0.46 and 0.50 or 0.48.

If the mechanical efficiency of the machine is 80 per cent, and hp_t is 2.30 for 127 rpm from Table 6, then $hp_c = 0.48 \times 38 = 18.2$.

$$hp_g = hp_c/\text{mech. eff.} + hp_t = \frac{18.2}{0.80} + 2.30 = 22.8 + 2.30 = 25.10$$

Therefore, a 25-hp motor may be used, but it will be overloaded by 50–100 per cent when the cutter becomes dull.

From the formula giving hp_c as a combined function of w, f, d, and N in Table 6,

$$\begin{aligned} hp_c &= 2.61wf^{0.78}d^{0.88}N \\ &= 2.61 \times 5 \times 0.020^{0.78} \times 0.187^{0.88} \times 127 \\ &= 2.61 \times 5 \times 0.0475 \times 0.229 \times 127 = 18.04 \end{aligned}$$

This value of 18.04 agrees favorably with 18.2 computed from the unit horsepower value shown above. Also 18.2/25.1 = 0.72 or the over-all efficiency of the machine and motor, including the hp_t.

The general formula for face milling five cast irons with high speed steel cutters and three cast irons with sintered-carbide cutters under specific conditions is given in Table 7 from which values of hp_c may be computed for any feed, depth, and speed.

TABLE 7. EQUATIONS FOR HORSEPOWER REQUIRED AT THE CUTTER WHEN FACE MILLING 1-IN.-WIDE ($w = 1$) BARS OF DIFFERENT MATERIALS

Material Cut	Type of Face-Milling Cutter	
	High Speed Steel (6–6–2) 58.3 fpm, $6\frac{3}{16}$ in. diam., 12-tooth	Sintered Carbide (K2S) 289 fpm, 9 in. diam., 16-tooth
	+9, +9, 6, 6, 2, 0, 0.07 at 45 deg	+7, +4, 6, 6, 2, 0, 0.07 at 45 deg
Malleable cast iron 123 Bhn 50,000 psi T.S.	$hp_c = 1.26wf^{0.7}d^{0.94}N$ (0.46)*	
Pearlitic malleable cast iron 200 Bhn	$hp_c = 1.6wf^{0.7}d^{0.97}N$ (0.56)	
Cast iron 170 Bhn 18,000 psi	$hp_c = 1.17wf^{0.7}d^{0.94}N$ (0.42)	$hp_c = 2.04wf^{0.72}d^{0.97}N$ (0.41)
Cast iron 217 Bhn 45,000 psi	$hp_c = 1.8wf^{0.7}d^{0.95}N$ (0.61)	$hp_c = 2.6wf^{0.78}d^{0.88}N$ (0.54)
Mechanite cast iron 190 Bhn 40,000 psi	$hp_c = 1.02wf^{0.82}d^{0.92}N$ (0.55)	$hp_c = 2.89wf^{0.77}dN$ (0.52)

The values in parentheses below each formula are unit hp_c for a depth of cut of 0.25 in., and feed of 0.010 in. per tooth.

Wattmeter Power For End Mills

The end mills of ¾ in. diam. had two teeth tipped with carbide of zero axle and radial rake. The net power at the cutter, hp_c, required to mill slots in SAE 3245 steel at 229 Bhn is $hp_c = 0.12f^{0.58}\ wdNn$, in which f is the feed per tooth, w the width of slots, d the diameter of cutter, N the revolutions per minute, and n the number of teeth in the cutter, all dimensions in inches. Also unit $hp_c = 0.12/f^{0.42}$; this gives values of unit hp_c as follows: 2.17 for $f = 0.001$, 1.63 for $f = 0.002$, 1.22 for $f = 0.004$, and 0.92 for $f = 0.008$ in. Care must be taken to provide ample chip space between the teeth.

When end milling slots in Mechanite cast iron at 190 Bhn (40,000 psi) with a 2-lip and 4-lip end mill, $hp_c = 0.34f^{0.87}wdNn$ and unit $hp_c = 0.34/f^{0.13}$. Values of unit hp_c for feeds in parentheses are as follows: 0.915 (0.0005), 0.835 (0.001), 0.765 (0.002), and 0.696 (0.004).

GRINDING MILLING CUTTERS

The grinding of milling cutters is one of the most important factors which the users of tools can control to obtain the maximum service. Milling cutters should be kept sharp at all times and be ground to proper angles. It is much more economical to regrind milling cutters as soon as they show slight signs of wear than to run the cutter until the teeth have become chipped or otherwise seriously damaged. Extreme care should be taken not to overheat the cutting edge during the grinding operation. Light cuts should be taken, removing not more than from 0.001 to 0.002 in. per cut. Ordinarily, grinding the teeth twice around the cutter will put the cutter in satisfactory condition if it is not too badly worn. To equalize the wear of the wheel, it is good practice to take a light roughing cut around the cutter, grinding all teeth in turn, then start a second cut on a tooth opposite the original starting point, again cutting all the way around. By repeating this method and taking a light cut, wheel wear is equalized, and the operator is able to keep the cutter cylindrical. Sintered-carbide teeth may be ground separately and checked by a dial gage.

Grinding machines used for grinding cutters vary from simple structures designed for sharpening a few of the more generally used types of cutters, to universal tool- and cutter-grinding machines with a range that meets practically all demands in cutter grinding. Most cutter grinders are equipped with horizontal double-end spindles which are mounted on a vertically adjustable head which also can be swiveled. Straight or cup wheels may be used on either end of the spindle.

For convenience in describing the common method employed in the sharpening of milling cutters, they may be divided into three general groups: plain cutters, side cutters, and form cutters. Plain cutters usually are ground on the land and face. Side cutters are ground on the peripheral land, the side lands, if necessary, and on the front and side faces. Form cutters usually are ground only on the face. A typical setup for grinding a relief on the land of a helical milling cutter having three teeth is shown in Fig. 55. A straight wheel cutting on its periphery is illustrated, although cup wheels cutting on the end also are used for this class of work. Straight wheels of small diameter actually produce a slight concave land, whereas cup wheels produce a flat land and are more desirable. Figures 56 and 57 illustrate the position of the cutter and the grinding wheel when grinding the land back

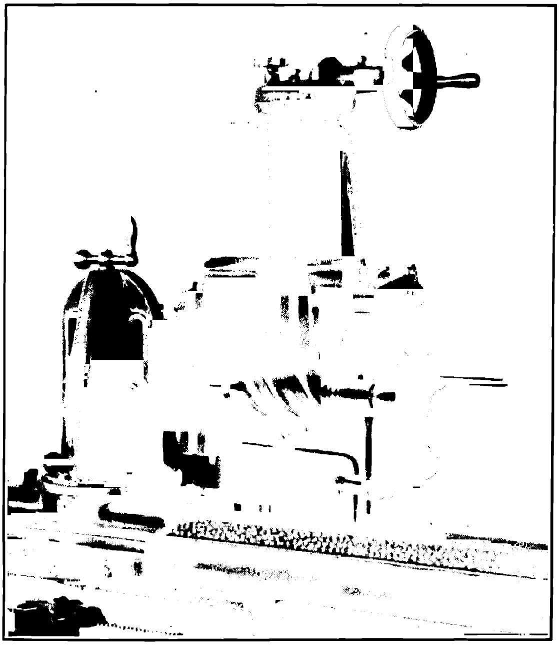


FIG. 55. A Setup for Grinding a Relief on the Land of a Three-Tooth Helical Mill on the Brown and Sharpe Tool Grinder.

A straight abrasive wheel is used, cutting on its periphery. The cutter is held on a mandrel supported in the universal head which is used instead of the motor-driven headstock. The universal head has both a horizontal and a vertical graduated dial for swiveling. The tooth rest supporting the face of the tooth being ground is attached to the table. The center of the wheel is set above the center of the cutter a distance X by the graduated elevating handwheel on the top of the column, in accordance with Fig. 56.

of the cutting edge on a plain milling cutter. Figure 56 represents the plain milling cutter having the land ground by the periphery of a straight disk wheel. To obtain the setting for the desired relief angle, the centers of the wheel spindle and work are first placed in the same horizontal plane. The tooth rest, consisting of a small strip of spring steel, is fastened to the table of the machine on which the cutter also is mounted and adjusted with a height gage to the same height as the work center. The head carrying the wheels is raised a distance x, Fig. 56, so as to form the angle θ between the horizontal and a wheel radius to the point of contact of the cutter tooth. The relief angle of the cutter is equal to the angle θ; then $x = \frac{d}{2} \sin \theta$. When θ equals 1 deg and d equals 1 in., $x_1 = \frac{1}{2} \sin 1 \text{ deg} = \frac{1}{2} \times 0.01745 = 0.0087$ in. Therefore, this value of x_1 for 1-deg relief angle and a 1-in.-diam. wheel would have to be multiplied by both the actual diameter of the wheel in inches and the desired relief angle in degrees in order to obtain x, the distance to raise the center of the wheel above the center of the cutter.

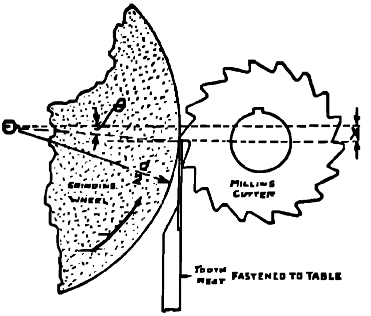


Fig. 56. The Position of the Cutter and the Straight Grinding Wheel When the Land on the Periphery of the Cutter Is Being Ground to a Relief Angle θ by the Periphery of the Wheel d Inches in Diameter.

The wheel is raised a distance X in inches above the center of the cutter.

$$X = \frac{d}{2} \sin \theta = 0.0087\, d\theta.$$

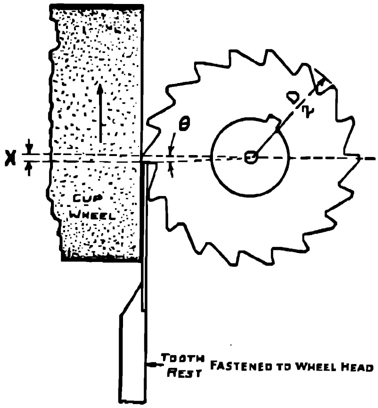


Fig. 57. The Position of the Cutter D Inches in Diameter and the Cup Grinding Wheel When the Land Is Being Ground to a Relief Angle of θ Degrees by the Face of the Wheel.

$$X = \frac{D}{2} \sin \theta = 0.0087\, D\theta.$$

Example: Find the elevation of the wheel center over that of the cutter if a 5-deg relief angle is to be ground by the periphery of a grinding wheel 6 in. diam. The constant x_1 for 1-deg relief angle and 1-in.-diam. wheel is 0.0087. The distance x, therefore, equals 5 deg × 6 in. × 0.0087 in. per in. per deg = 0.261 in. Therefore, the wheel head should be raised 0.261 in.

In sharpening the land on the periphery of the teeth of the milling cutter with a cup wheel, the angle θ is as indicated in Fig. 57. In this case, the diameter D of the cutter is used instead of the diameter d of the wheel as in the example cited above. Also the tooth rest is fastened to the wheel head instead of the table.

Example: If a 3-in.-diam. cutter is to be ground on the periphery to have a 7-deg relief, the wheel head to which the tooth rest is fastened is first placed on center, using a surface gage, and then is lowered a distance equal to x, as shown in Fig. 57, in which x = 3 in. × 7 deg × 0.0087 in. per in. per deg = 0.1827 in.

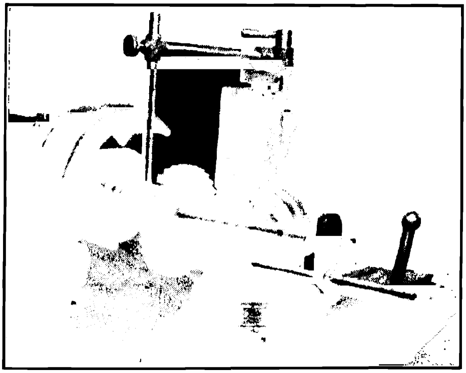


Fig. 58. A Setup on the Norton Universal Tool and Cutter Grinder for Grinding the Side Land of a Side Milling Cutter.

A universal vise or attachment which swivels in a horizontal and vertical plane is used to hold the mandrel on which the cutter is forced. The cutter is tilted on the vertical scale to give a side relief of approximately 4 deg, and swiveled on the horizontal scale from $\frac{1}{4}$ to $\frac{1}{2}$ deg to prevent the drag of a side-cutting edge, as illustrated in Fig. 43. A flaring-cup grinding wheel 4 in. diam. by $1\frac{1}{4}$ in. deep, Norton 3846J, with a vitrified bond, is used.

In grinding the land, the general practice is to rotate the grinding wheel toward the cutting edge, as indicated by the arrow in Fig. 56. No burrs are left on the cutting edge by this practice. The cutter must be held against the tool rest by hand to overcome the tendency of the wheel to rotate the cutter away from the tooth rest.

The land on the side of the tooth of a side-milling cutter is being ground by a cup wheel on the tool- and cutter-grinding machine in Fig. 58. The cutter is held on a mandrel which, in turn, is clamped in a combination attachment which permits swiveling the cutter in both the horizontal and vertical planes.

A setup for grinding the radial face of a formed cutter for fluting reamers is shown in Fig. 59. A thin dish-shaped grinding wheel is being used in order to reach the bottom of the chip space without interference. The face of each tooth is ground by passing the cutter with a steady motion past the wheel, using the hand traverse. After making light contact between the wheel and the face of the tooth, a first and second grind on all teeth around the cutter is made without moving the cross-feed, as this would change the radial line of the cutter face. If a heavier cut is needed, the cutter is rotated forward by slightly advancing the tooth rest.

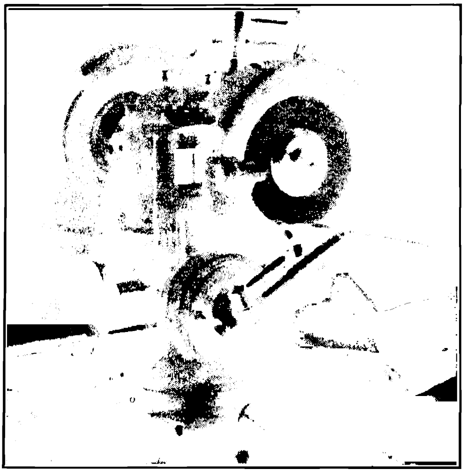


FIG. 59. Grinding a Formed Cutter for Fluting Taps and Reamers on a Norton Universal Tool and Cutter Grinding Machine.

The cutter is mounted on a mandrel held in a combination attachment or universal chuck. A Norton 3860J vitrified, dish-shaped grinding wheel 6 in. diam., ½ in. thick, and of 1¼ in. bore is used. The tooth rest bears against the back of the tooth being ground. The wheel face is first located over the center of the vise V. After inserting the mandrel on which the cutter is mounted, the cutter is rotated until the radial face is in contact with the wheel face. While in this position, the tooth rest is placed and fastened. A diamond nib for truing the wheel is in position in the attachment in front of the left edge of the wheel.

Universal heads with graduated dials are used to secure proper angles for grinding milling-cutter teeth, as shown in Fig. 60.

The **grinding wheel** for the grinding of milling cutters must be free cutting so as not to "burn" the cutting edge. For the same reason, the cut must be light and never forced. Cutter grinding usually is done dry because of the inconvenience of the coolant. If the wheel is too soft, it wears rapidly and there is difficulty in keeping the cutter in a true cylindrical form or securing a sharp cutting edge.

For cutter grinding, wheels of aluminum oxide grain 46–60 are best suited for both high speed and carbon steels. Finer wheels are more likely to burn the work. Wheels most commonly furnished for grinding solid plain milling cutters are the A46 BJ vitrified, although A60 K5BE vitrified is satisfactory, especially in dish shapes. A keen edge is obtained by continuing with a light cut with a C320J8L shellac wheel. Form cutters often are ground with a dish wheel, usually A60 BJ or BK, vitrified. Norton wheels most commonly furnished for inserted-tooth milling cutters of high speed steel are the A46 grade J or K vitrified. Sometimes a coarser and softer wheel, such as A36 BI, is best. The cutting peripheral speed of these wheels should be between 4,000 and 5,000 fpm. (See Norton Co., *Grits and Grinds*, March, 1949.)

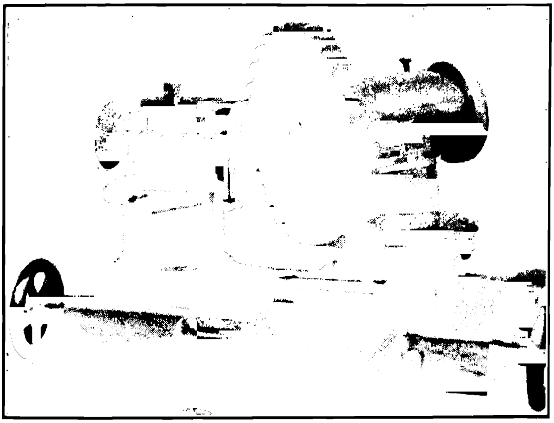


FIG. 60. Grinding the Relief and Corner Bevel on the Inserted High Speed Steel Teeth of a 20-in.-diam. Face Mill, Using a Straight Cup Wheel.

The tooth rest is on the lower side of the tooth. The center gage by which the tooth rest is set central with the wheel center is shown on the wheel head. The standard Cincinnati head for large face mills for cup-wheel grinding is being used. This has three graduated scales, one horizontally near the base, a second on an incline above the base, and the third on the forward end of the spindle housing behind the cutter. The head is of cast aluminum and the head spindle is mounted on Timken roller bearings. A Carborundum Co. straight cup wheel is being used, 5 in. diam., 1½ in. wide, 1¼ in. hole, of Aloxite grain 401, grade C, bond No. 25.

In grinding tools made of sintered carbide, diamond wheels are used, as suggested in Chap. V.

QUESTIONS

1. Distinguish between a plain and a universal milling machine.

2. In what way is milling superior to planing or shaping?

3. Describe how a milling machine may be used on tool work where a drill press was formerly used.

4. Name the various types of milling machines.

5. Two milling jobs are set up similar in all respects except in number of teeth in the cutter. What difference in power will be observed? Explain.

6. Describe the three systems used in milling-machine indexing.

7. Describe the milling of the tops of automobile cylinder blocks.

8. A vertical universal milling attachment is used in cutting a worm. If the pitch diameter is 3.5 in. and the lead is 0.5 in., find the angle at which the vertical head or cutter must be set.

9. A dividing head has 40 teeth in the worm wheel. Determine the setup for indexing 65 divisions if $R = 40$ and the 39-hole circle is used.

10. If a dividing head has 40 teeth in the worm wheel, determine the setup to index 379 divisions. Circle 20 and regular Brown and Sharpe change gears are provided.

11. A side milling cutter makes 90 rpm, is 6 in. diam., has 28 teeth, and feeds 2 in. per min when cutting a slot 1 in. deep. Find the feed per revolution and per tooth.

12. The lead screw of a milling-machine table has 4 threads per in. A helical gear (5 in. *PD*) is to be cut. The angle of helix is 9 deg 56 min. Find the ratio of gearing between the dividing head spindle and table screw.

13. In milling the outside edge of an aluminum tub on a No. 2B Milwaukee miller, a speed of 700 rpm and a feed of 45 in. per min are used. A plain high speed steel milling cutter 3½ in. diam. by 1 in. bore by 1¼ in. face, having 16 teeth, is used. The cut is ¼ in. deep and 3⁄16 in. wide. Find the surface cutting speed, the feed per tooth in inches, and the cubic inches of metal removed per minute.

14. Cylinder blocks are being faced on a Sellers planer-type miller. The facing cutter, 12 in. diam., has 54 teeth of high speed steel, a cutting speed of 70 fpm, a depth of cut of ⅛ in., and a feed of 12 in. per min. What is the feed per tooth? What is the feed in thousandths of an inch per spindle revolution?

15. Referring to Table 4, determine the horsepower per cubic inch of metal cut per minute when cutting with a sulphurized mineral oil, No. 10, the SAE 1020 steel on the out-cut, when the width of cutter is ½ in., the depth of cut ¼ in., and the feed per tooth 0.012 in. The side cutter used has a 15-deg rake angle. Determine the horsepower per cubic inch of metal cut per minute if the feed per tooth is reduced to 0.004 in., other conditions remaining the same.

16. Find the number of speeds of a milling machine if the range of speeds is 15–1,500 rpm, the speeds are in geometric progression, with a ratio of 1.194. Determine all speeds.

17. Name and define the five methods of manufacturing as regards milling fixtures.

18. Explain the relation between hp_g, hp (motor output), hp_n, hp_c, and unit hp_c.

19. From Table 6 give the complete cutting conditions for unit values of 0.87 and 0.43. What accounts for the difference in these values of unit hp_c?

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CHAPTER IX

SAWING

DEFINITION

The sawing or parting of metals is accomplished commercially by using saws which consist of thin disks of metal with cutting teeth on the periphery, or a strip of metal with teeth formed on one edge. Usually the width of the strip is slightly less than the outer side-edges of the teeth of the saw so as to eliminate binding between the cut surfaces and the sides of the saw. This is accomplished by "setting" the teeth alternately to the side, or by "hollow grinding" the blade below the edge of the cutting teeth. The width of the groove cut by the saw blade is called the **kerf.**

SAWING MACHINES

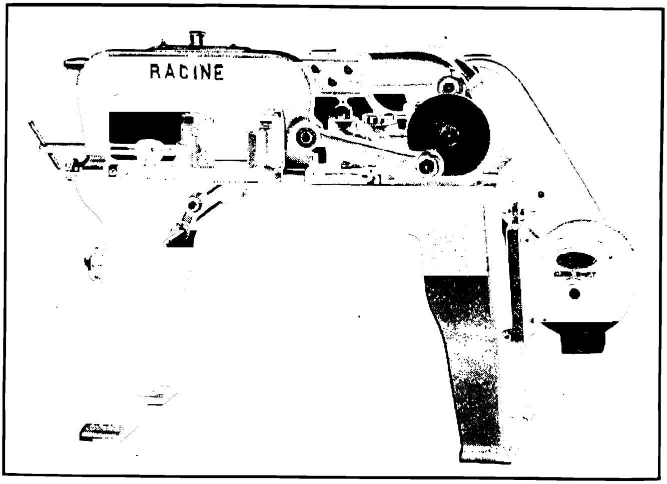
Three types of metal-sawing machines are in common use: the hack saw, band saw, and circular saw.

1. The **hack-sawing machine,** Fig. 1, employs a short, straight strip of steel or blade having teeth formed on one edge. The blade, mounted in a frame under a tensile load, is reciprocated back and forth over the work. It is forced against the work on the cutting stroke, but lifted on the return stroke to prevent the dragging of the cutting teeth over the work.
2. The **band-sawing machine** employs a long endless strip of steel with teeth formed on one edge carried over two large-diameter rotating wheels, Fig. 5.
3. The **circular-sawing machine** employs saws of the disk type, Figs. 10 and 11. These saws are divided into two groups — the cold-sawing machine and the high-speed friction or abrasive disk machine.

The Hack-Saw Machine

The power hack-saw machine in its simplest form provides a means for clamping the work to be cut and a means for reciprocating, by mechanical power, a frame carrying a hack saw. The saw bears down on the work during the cutting stroke but is raised to clear the work during the noncutting stroke.

To furnish a feeding pressure on the cutter, the saw is usually mounted above the work to be cut. In the simple **gravity-feed** machine, the weight of the saw-frame guide or head furnishes the pressure of the saw into the work. The feeding pressure is constant, and the frame and head are allowed to be fed downward against the work by a pair of dogs alternately engaging a fine-tooth ratchet. This permits the saw frame and head to be lowered only a given distance for each stroke of the saw.



Courtesy Racine Machine Tool Co.

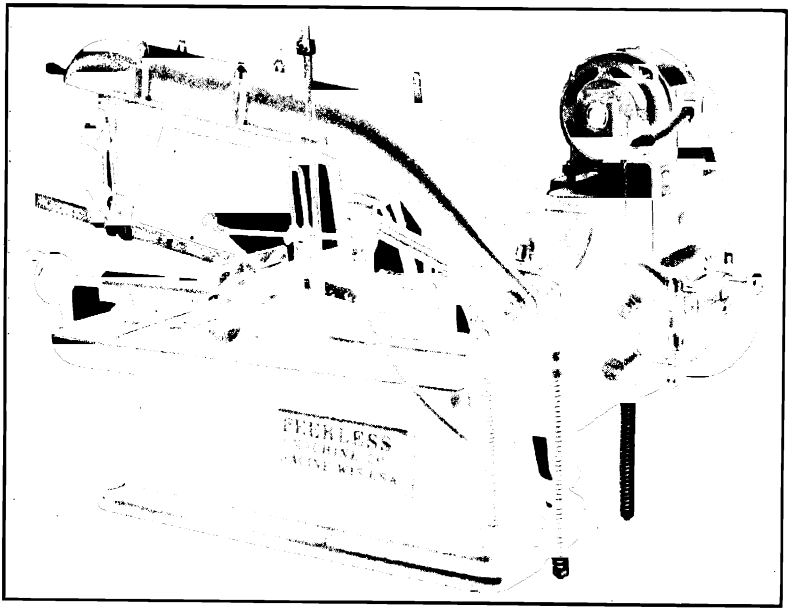
Fig. 1. The Racine "Dry Cut" Utility Hack-Saw Machine.

This represents a simple type of hack saw for general run or small-shop maintenance and laboratory work. It has a 6 in. × 6 in. capacity and uses blades 14 in. long by 1¼ in. wide with four or six teeth recommended for thick work. The stroke is 5 in. long with 70 and 100 strokes per min available. A ½-hp motor of 1,200 rpm is used. A simple piston pump supplies oil under pressure to a main feed cylinder. The rate of feeding the saw into the work is controlled by a graduated dial operating a small throttling valve.

Additional **sliding weights** may be clamped on the back of the saw-frame head to obtain variable feeding pressures on the blade for cutting different classes of work. The feeding pressure on the cutter is of great importance from a production standpoint.

The small saw of Fig. 1 is a motor-driven hydraulic feed machine having two speeds, the slower for the harder metal. This is for dry cutting and for use in small laboratories or shops for miscellaneous work.

The power hack-saw machine, Fig. 2, employs an **adjustable spring-tension feed pressure** to augment the weight of the frame and head. Two sets of dogs or ratchet fingers engage a hardened-steel ratchet fastened to the head. A coiled spring causes the dogs to force the rack and saw down at each stroke, although an arrangement is provided to permit one set of dogs to be in mesh with the rack while the other set is transferred to the next notch when the saw is raised on the noncutting stroke. In this type of machine a blade will last from 6 to 8 hr when sawing mild steel at a rate of 60–90 sq in. per hr. If hard spots are encountered, or if the blade grows dull, the pressure remains the same but the rate of feed is reduced to compensate for the changed conditions. If the saw grows dull, the feeding pressure should be increased by raising the feed-control lever to keep the cutting time nearly constant. With the saw blade at its highest point when the machine starts after being loaded, it will not drop to the work and break the blade, as the automatic feed carries it down at

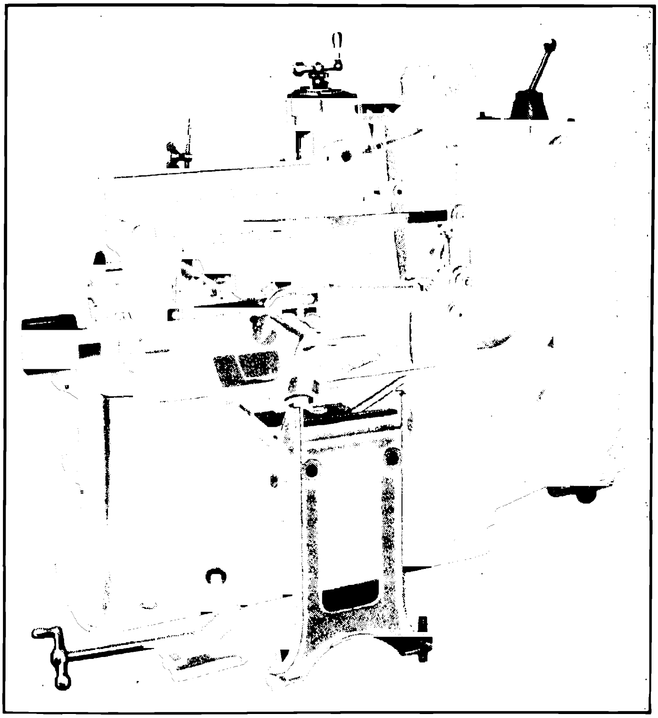


Courtesy Peerless Machine Co.

FIG. 2. The Peerless High-Speed Standard-Type Metal-Sawing Machine with Spring Pressure Feed.

This machine has a 6-in. stroke, in two sizes of 9-in. × 9-in. and 13-in. × 16-in. capacity. It has a multiple V-belt drive from motor to driven sheave, which then drives through a fully enclosed three-speed gearbox. The spring feed pressure is increased by raising the feed-control lever on rear side to give a load from 0 to 225 lb. When the saw reaches the bottom of its traverse, determined by the position of the lower gage stop, the starting lever back of the crank is shifted, tripping the limit switch and stopping the drive motor and machine while the head is automatically raised to its upper position. After clamping the work in the vise, the machine is started by moving the control lever to starting position. The single starting lever controls the motor and engages and disengages the feed unit.

a fixed rapid rate until the work is reached, when the selected feed automatically commences. Two sets of coil springs are arranged on levers to balance the weight of the head about its supporting axis.



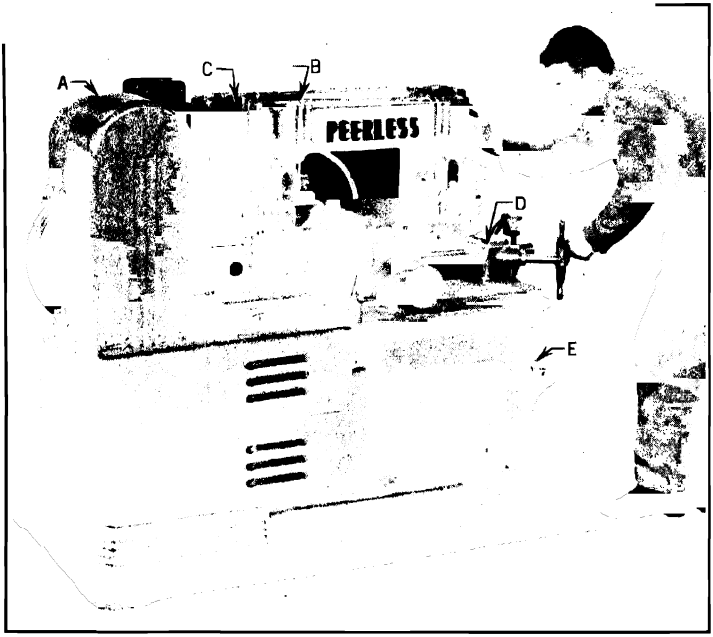
Courtesy Armstrong-Blum Manufacturing Co.

FIG. 3. A No. 6A (Capacity 6 in. × 6 in.) Marvel High-Speed Production Hack Saw.

Equipped with ball bearings and 1½-hp direct motor drive through a four-speed transmission box of 149 (for mild steel), 120 (for free-cutting alloy steel), 92 (for annealed steel and tough alloys), and 75 (for annealed high speed steel and hard steels) strokes per min. A lower speed series may be obtained for special purposes.

This machine is equipped with full automatic bar feed so that, for example, a 20-ft bar of 3-in. round SAE 1045 steel can be cut into 30 duplicate-length pieces each 8 in. long in 60 min after the operator sets up the job and loads the bar into the machine, which requires about 5 min. No further attention is needed, as the machine automatically stops when the bar is cut. The blade cuts on the draw stroke and is lifted ⅛ in. on the return stroke. A quick return motion of the saw saves approximately one-third of the total cutting time.

In the hack-sawing machine, Fig. 3, the head carrying the saw blade is always horizontal or parallel with the bottom of the vise, so that the saw blade is horizontal through the entire vertical traverse. The saw frame is fed downward by means of a lead screw with a combination **positive and friction dual-power feed** that can be used either independently or simultaneously in combination. The positive feed is safe but is ordinarily cut out, when overloads occur, by the slipping of a friction disk between a ratchet and the screw. Convenient hand feed also is provided. This machine is equipped with a four-speed transmission box so that speeds suitable for various materials can be obtained instantly. It will feed automatically and cut up long bars into duplicate-length short pieces without the attention of an operator, or it can be used as a plain machine for miscellaneous work simply by dropping off the belt of the bar-feed mechanism on the left side of the machine.



Courtesy Peerless Machine Co.

Fig. 4. The Peerless Hydra-Cut Hydraulic Hack-Sawing Machine for Fast Production Work.

The Racine Shear Cut hack-saw machine is provided with a **positive progressive screw feed** which, when once set at the proper feed for any size or kind of metal, will continue to make each successive cut in exactly the same length of time. Production is, therefore, positive and is not subject to uncertain pressures of gravity, spring tension, or friction feeds. The cut can be fixed at 0.001–0.025 in. per stroke, and three change speeds, giving 60, 90, and 135 strokes per min, are provided.

The Peerless Hydra-Cut hydraulic-feed hack saw, Fig. 4, is made in three capacities to take work 7 in. × 7 in., 11 in. × 11 in., and 14 in. × 14 in. Each machine has three speeds from a 2- or 3-hp motor of 50, 85, and 125 for the larger machines and 60, 100, and 140 strokes per minute for the 7-in. machine shown. The length of the stroke is 6 in. The small machine uses blades 14–17 in. in length. The saw blade is backed by a heavy steel plate to prevent deflection of the blade. The saw and its frame are fed into the work by hydraulic cylinders at each end of the frame. *A* is the driving motor; *B* the four-sided saw frame and back plate; *C* the arch and dual cylinders frame; *D* the work clamping vise and screw; *E* the feed pressure control; *F* the hydraulic-feed unit housed in base. The blade is fed into the work by means of an oil pressure built up on a piston in a cylinder by an oil motor. This oil motor regulates the speed with which the head approaches the work (rapid traverse), as well as the cutting pressure. The oil-motor pump also can be used for holding the head in its uppermost position when changing the work in the vise.

A 9-in.-diam. mild steel bar can be cut through in 13–20 min. A 6-in. pipe with ½-in. walls can be cut in 1½ min. Only coarse-tooth blades having 4 or 6 teeth per in. should be used.

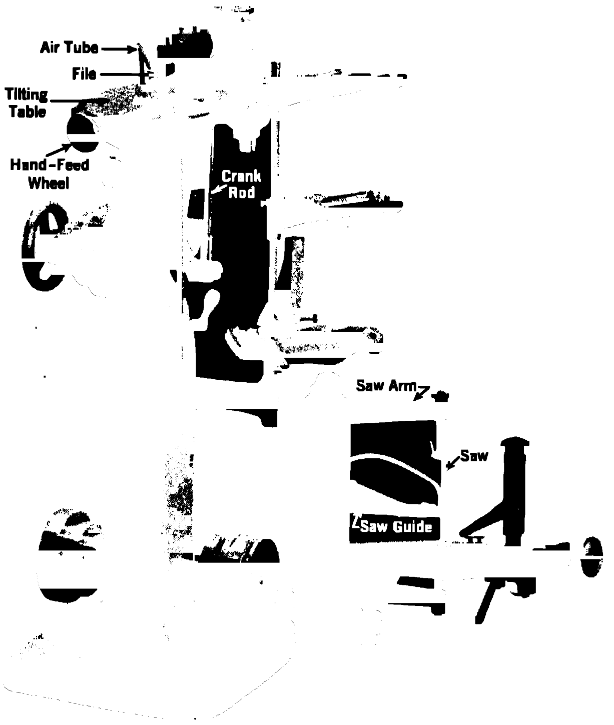
Saw and Filing Machines

Small saws are often used on machines for die work. Machines of this character may be of the bench type, or the floor type illustrated in Fig. 5. These machines usually are rather universal in their application, and the small saws are often interchangeable with files. The file is supported in the lower head and extends through an opening in the table. The table may be tilted to any desired angle so that the clearance surface on dies or the edges of sheet metal, etc., can be filed according to size and shape. The work may be fed slowly and uniformly into the saw by a hand-operated screw.

Band-Sawing Machines

Band-sawing machines are designed for a wide variety of work, and range from the small bench type, using a ¼-in.-wide blade, to heavy-work machines designed to cut solid material up to 12 in. sq. These various machines require the use of certain widths of band-saw blades.

A light-duty band saw for wood and metal is shown in Fig. 6. The long, endless band-saw blade passes over the periphery of two large wheels arranged in the same plane but some distance apart. The table, on which the work to be cut is supported, is located between the two wheels about the saw as it passes downward from the upper wheel. These tables usually may be tilted to any convenient angle from the horizontal. This machine is made as model 12 with one high speed for



Courtesy Cochrane-Bly Co.

FIG. 5. A Filing and Sawing (Insert) Machine for Die Work and Small Parts.

This No. 2-B machine is arranged to use files supported at the upper end, standard 8-in. hack-saw blades, or pieces of narrow band saws supported at both ends, to machine work up to 4 in. thick. Files of a variety of shapes such as round, square, flat, 3-square, knife, are used. The position of the saw or file in the work is adjustable. Four speeds from 60 to 426 strokes per min, and automatic relief for saw or file on the return stroke, are provided.

cutting wood; as model 13 with a high and a low speed for cutting all material including hard metals and steel up to 3 in. in thickness; and as model 14 with a high and a low speed and with a sliding table, swivel vise, and gravity feed for cutting all materials. Each model also is made with provision for handling long lengths such as cutting off long bars or for slitting long sections. In some machines, instead of swiveling the table, the column and blade are tilted. Also, instead of feeding the work on the table into the saw, the column and saw are fed into the work. Feeding may be done by hand or conveniently adjusted to any mechanical rate. Band saws are used with hand, power, or gravity feed.

A well-designed band saw is illustrated in Fig. 7 at the left. At the right is shown a close-up of the band-saw welding device. With such saws a portion may be removed from the center of a plate by cutting the saw, passing it through a drilled or punched hole, and rewelding the saw for the sawing operation.

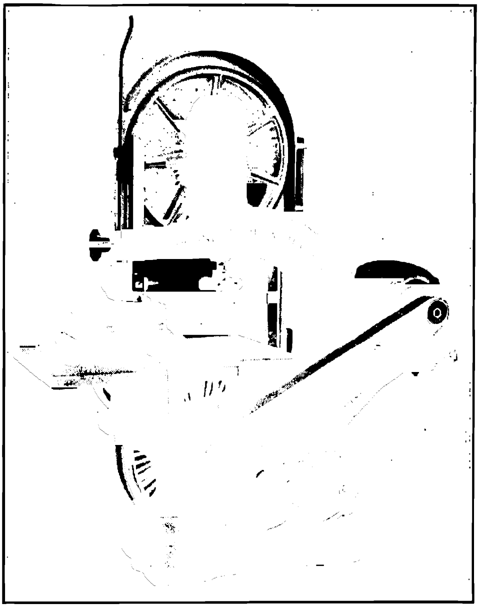
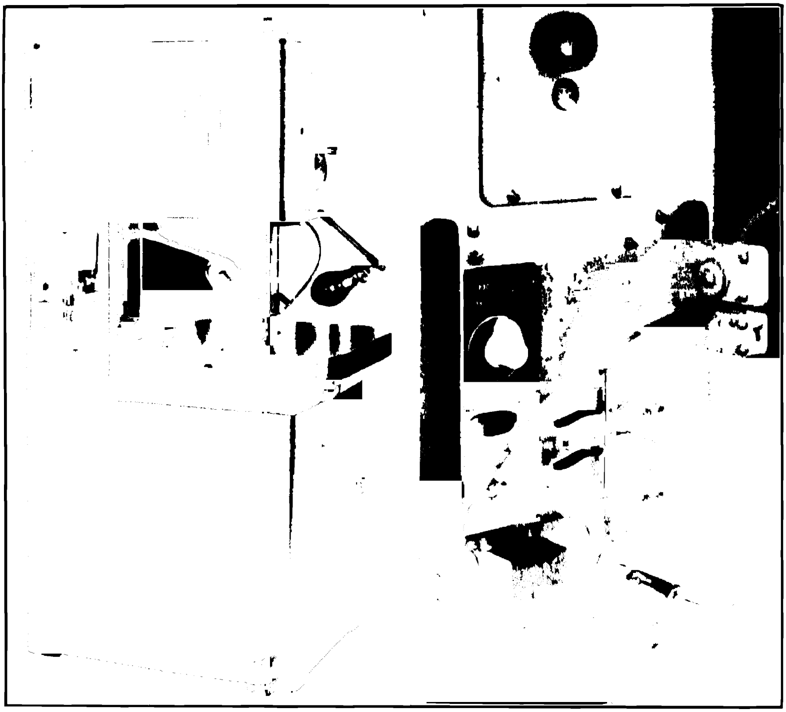


FIG. 6. The Racine Duplex Band Saw for Bench Mounting.

A general-purpose machine for cutting metals, composition materials, and wood. A ½-hp motor drives the band saw at a high speed of 1,800 fpm for cutting wood, fiber, Bakelite, aluminum, brass, and other soft metals, or at a low speed of 80-225 fpm for cutlery, hard metals, and steel up to 3 in. in thickness. These machines are particularly adapted to cutting thin stock, tubing, light angles, etc. A gravity-feed vise is mounted on the table.

The DoAll Contour-matic, introduced for manufacturing, provides a stepless speed range from 40 to 10,000 fpm for all industrial materials. It uses a wide variety of bands including filing bands and polishing bands. Some bands are abrasive tipped and others sintered-carbide tipped for appropriate work. The machine is operated hydraulically.

Band saws may be used for cutting long bars, tubes, or gates off brass, bronze, and copper castings, in which case hand feeds are often used because of the difficulty in clamping the parts of irregular



Courtesy Grob Brothers.

FIG. 7. The Grob NS-18-10 Band Saw.

The machine at the left is equipped with a five-step pulley and back-gear speed drive saw welding unit and push button control

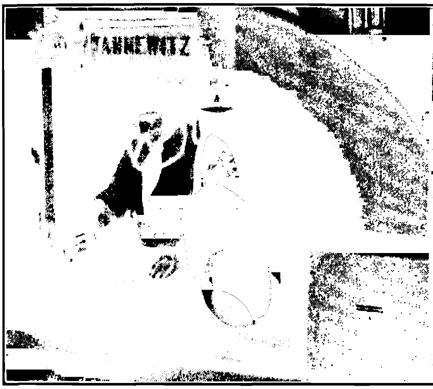
The close-up view at the right shows the cut-off tool for squaring the blade the electric butt welder for welding and annealing the blade, and an abrasive wheel for removing the flash so the saw will pass through the slotted gage at the left

shape. They can cut work that cannot be reached conveniently with a circular or hack saw. Often surfaces are left smooth enough so that further smoothing operations are unnecessary.

Band saws are not only labor saving as to time of cutting, but they also are economical, especially when the material cut is of high cost, such as stainless and annealed tool steel, by reason of the small kerf or waste due to the thinness permitted in the saws. Two typical band-saw jobs are shown in Figs. 8 and 9.

Sawing Machines Employing Disk Saws

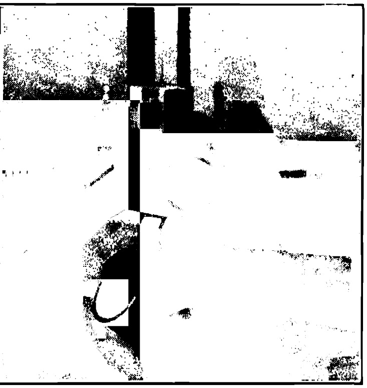
Cold saws: A metal-cutting machine in which a disk saw similar to a thin milling cutter is used to cut off large pieces of solid stock is illustrated in Fig. 10. This is a precision machine tool embodying the latest principles of design. It is used extensively where large quantities of pins and shafts are cut. The multiple cutting illustrated, in which a 60-deg V yoke is used to hold the work, increases production many times over that of the single cut and greatly reduces the cost. A 90-deg included angle V block is supplied in which round, square, or rectangular stock may be clamped while being cut. Special types of blocks or clamps are used to meet the requirements of shaped structural steel so as to hold the work closely together and at the same time close to the saw, so that a minimum length of feeding stroke is required in making the cut.



Courtesy Tannewitz Works.

FIG. 8. The Tannewitz Type GH 36-in. High-Speed Band Saw, Shown Set Up for Sawing 16-Gage Sheet-Metal Parts for a Furnace Damper.

This is done at 1,200 rpm, or approximately 12,000 fpm, which is friction sawing speed. Steel as thick as ½ in. may be handled. The band-saw blade is ⅝ in. in width, of all spring tempered steel with ⅛ in.–¼ in. tooth spacing, well set.



Courtesy Grob Brothers.

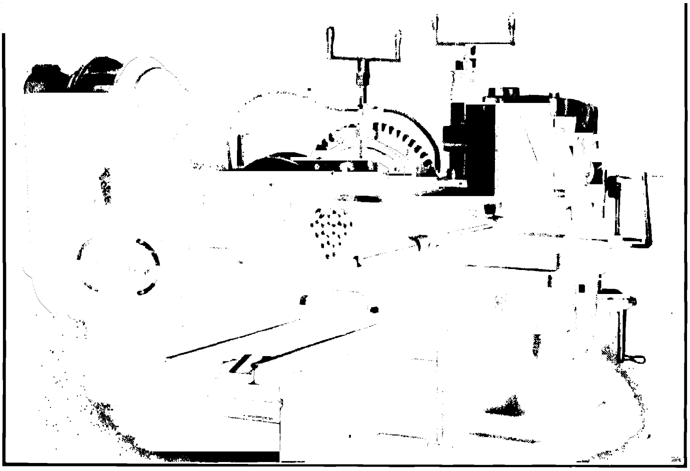
FIG. 9. A Section of a Tube is Being Removed on a Band Saw.

The work is held in a vise above the table. The saw is supported by the upper guide just above the work, and the lower guide is brought from beneath the table surface to just below the work.

Friction disk saws: In the metal-cutting saw employing **friction disk,** Fig. 11, cutting speeds from 16,000 to 22,000 fpm are used. Large sections are cut in two in but a few seconds by forcing the saw with a plain or notched periphery into the work by a hand lever, foot pedal, or power feed.

This is a small-size machine designed to meet the wide need for efficient cutting off of smaller unhardened structural shapes, tubes, and bars. Water cooling the saw is recommended for all classes of work.

An 8-in. I beam may be cut off in this machine in about 15 sec but on the larger machines in about 5 sec. Some of the larger machines are equipped with a rotating attachment for cutting large rounds and squares. The stock is rotated on its axis parallel to that of the blade at a speed of about 3 or 4 rpm. This prevents the blade from coming into contact with any large area of metal at one time and thereby reduces the load on the motor, produces a much cleaner cut, and increases the capacity of the saw about 200 per cent.



Courtesy Cochrane-Bly Co.

FIG. 10. The Cobly No. 55 Metal-Sawing Machine.

The machine is arranged for cutting a bundle of round bars. It is equipped with a 7½-hp motor driving through multiple V belts, and a quick-acting compound toggle clamp for clamping the bars in the 60-deg fixture for multiple cutting. Four speed changes of the saw providing speeds of 42, 60, 75, and 90 fpm are available, and 16 feed changes varying from ½ to 10 in. per min are provided. The machine carries a 24-in.-diam. saw blade with 54 inserted teeth of high speed steel. The plate is 3⁄16 in. thick and the kerf is ¼ in. It will cut stock 7 in. diam., 6½ in. sq., 10-in. I-beams, and 5-in. by 10-in. rectangular sections. By using the 60-deg fixture for multiple cutting, 76 ½-in.-diam. bars, 26 1-in.-diam. bars, 13 1½-in.-diam. bars, 8 2-in.-diam. bars, or 4 3-in.-diam. bars can be cut at a time.

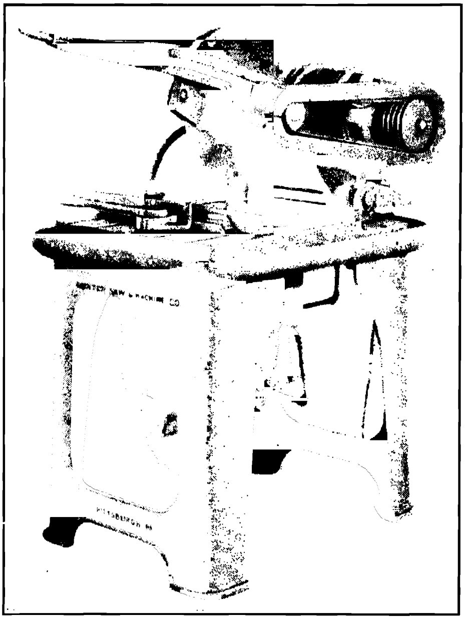
Abrasive saws: The metal-friction saw may be replaced by and is interchangeable with a thin abrasive wheel operating at 10,000–16,000 fpm for cutting extremely hard materials, such as hardened tool steel, drill rod, and materials which are very abrasive in character.

SAWS

Metal-cutting saws may be divided into **four principal types**: (1) hack saws, (2) band saws, (3) disk or circular saws, and (4) abrasive disks (cold and friction).

Hack-Saw Blades

Hack-saw blades are usually made up of thin strips of steel with teeth milled on one edge by gang cutters. These blades are comparatively short, usually with a hole in each end by which they are attached to the frame. The blades are held under tension while they are being fed into the work. The teeth of a hack-saw blade are arranged for cutting in one direction. When the blade is held in a hand hack-saw frame, such as that illustrated in Fig. 12, the teeth point away from the operator so that the cutting is done on the forward stroke. In machine cutting, the teeth usually point toward the machine and the cutting is done on the pull stroke.



Courtesy Hunter Saw and Machine Co.

FIG. 11. The No. 6 Hunter High-Speed Metal Cut-off Saw.

The 18-in.-diam. ⅛-in.-thick saw is driven at 3,900 rpm (18,500 fpm) by a 5-hp motor through multiple V belts. A separate ⅛-hp motor drives the coolant pump. A hand lever rocks the swing frame which feeds the saw through the work. An adjustable stop is provided so the saw will just clear the material being cut. Miter as well as straight cuts can be made. A 16-in.-diam. abrasive wheel ⅛ in. thick is interchangeable with the steel saw, and cuts solids up to 2 in. diam.

Most blades have teeth with no rake. Some have positive rake and some negative rake. The tooth with rake has a tendency to " hog in " whenever it comes in contact with thin edges or walls of work having an acute angle. Blades having negative rake require more pressure in cutting, but are often more satisfactory for cutting parts having thin walls and, in general, for work that presents little resistance to the pressure of the teeth.

Steel for hack-saw blades: Hack-saw blades are made of carbon tool steel, semihigh speed steel, and high speed steel.

Up to the last few years, the semihigh speed steel blades have been most generally used. They are made in the all-hard blade or the hard-teeth and soft-back blade. As soon as the teeth of the latter are worn out, the blade is replaced by a new one. Blade breakage is reduced, however. **High speed steel blades,** during the past few years, have replaced the semihigh speed steel blades, inasmuch as they are able to stand a greater speed under a heavy feeding pressure. They will cut five to ten times more than, and almost twice as fast as, the tungsten-steel blades.

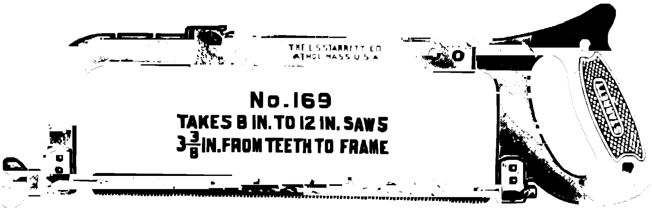

THE L.S.STARRETT CO
ATHOL MASS U.S.A.
No.169
TAKES 8 IN. TO 12 IN. SAWS
$3\frac{3}{8}$ IN. FROM TEETH TO FRAME

FIG. 12. The Starrett Hand Hack-Saw Frame No. 169.

Adjustable by pawl to take 8-in.- to 22-in.-length saws. The blade indexes 90 deg to cut in any one of four directions. For general all-round work, saws with 18 teeth per inch are recommended for hand frames.

The set of a saw: In order to make the kerf or slot cut wider than the thickness of the saw blade, the teeth of the saw are set. A common way of setting teeth is to bend one tooth slightly to the right, and the next slightly to the left. These are known as **regular alternate** teeth. In some fine-tooth saws, every pair of teeth is **set** alternately right and left, producing a style known as **double alternate.** Another standard method is to have one tooth straight, the next bent to the left, the next bent to the right, and the next one straight, etc. This style of setting is known as **alternate and center.** The **wavy set** blade has the individual teeth alternately offset slightly, and then the edge of the blade is crimped right and left, there being three or four crimps to the inch. This type of saw, with very fine teeth, made for hand and power hack saws and for band saws, is used almost exclusively for cutting thin sheets and tubes.

Number of teeth: In metal cutting with modern hard-edge saw blades, it is important that the proper number of teeth per inch be used for different kinds and shapes of metal. When thin stock is to be cut, a number of teeth per inch should be selected so that at least one tooth always is riding on the surface. If the thickness of the stock is less than the pitch of the saw teeth, two teeth will straddle the edge, causing an excessively heavy load to be borne by one tooth, resulting in breaking out the tooth or even breaking the blade. A fine-pitch saw should be used when cutting thin sheets or tubes.

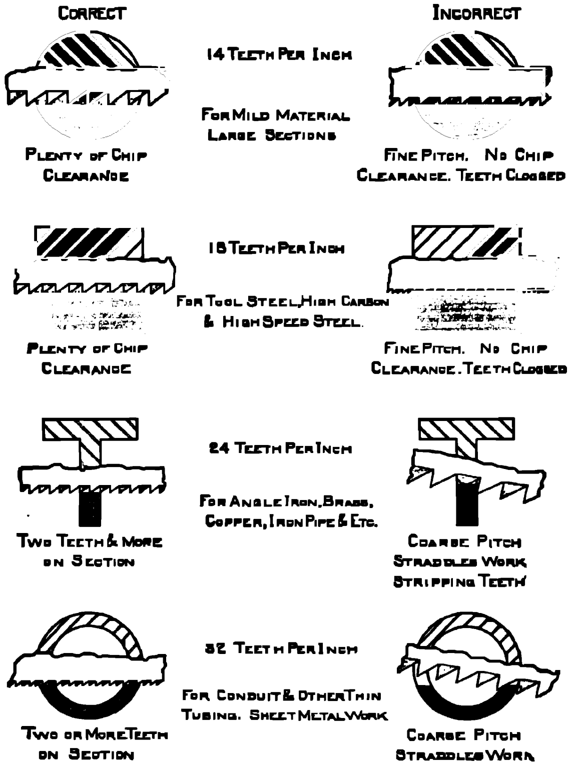
If the material being cut is thick so that several teeth will be cutting simultaneously, a coarse-pitch blade should be used to provide ample chip space between the teeth for the long chip being removed. Coarse teeth should be used on soft metals, the length of cut being constant. Fine-pitch teeth cutting thick stock become clogged with chips and either do not cut or become overheated. Incorrect and correct sawing conditions, which involve the number of teeth and the thickness or hardness of the stock cut, are illustrated in Fig. 13.

Hand hack-saw blades of semihigh speed steel are made in lengths of 8, 10, and 12 in. and 0.025 in. thick with 14, 18, 24, or 32 teeth per in. The high speed steel blades for hand frames are made in 10- and 12-in. lengths. Each saw blade is designated by its length, width, thickness, and number of teeth. Each length usually has a **regular** number of teeth per inch, a **medium** number, a **fine** number, and a **tubing** or extra-fine number.

Hack-saw blades for power hack-saw machines also are made of semihigh speed steel and high speed steel from 12 to 24 in. long, and 0.025 in. to 0.065 in. thick, with 4, 6, 8, 10, 12, 14, or 18 teeth per in. High speed steel blades are gaining rapidly in use and are recommended for all production work.

The regular teeth are recommended for cutting soft steel, cast iron, and bronze. The medium teeth are recommended for cutting annealed high-carbon and high speed steel. Fine teeth are recommended for cutting solid brass, iron pipe, heavy tubing, etc. Tubing teeth, sometimes made with a wavy set, are recommended for cutting thin tubing and thin sheet metals. Current practice in modern machines is to use coarse teeth as much as possible, even for cutting small stock or thin tubes.

In **specifying a hack-saw blade**, it is essential to state the length, width, thickness, and number of teeth per inch. The material to be cut, the material of which the saw is made, and the use — whether in a hand frame or light-, medium-, or heavy-duty power machine — are determining factors.



Courtesy L. S. Starrett Company.

FIG. 13. Illustrations Showing Correct and Incorrect Number of Teeth Used in Hack-Saw Blades.

The fine teeth lack chip space, and the coarse teeth may straddle the work.

Blade lengths for stock sizes are used as follows:

Stock up to 3 in., use 10-in. blades
" " " 4 " " 12 " "
" " " 6 " " 14 " "
" " " 9 " " 17 " "
" " " 12 " " 21 " "
" " " 15 " " 24 " "

Cutting speeds and feeding pressure: General recommendations for **cutting speeds** for semihigh speed steel blades in power hack-saw machines are as follows:

All mild steels and soft metals should be cut at the normal high speed of the machine, which is 125–135 strokes per min.

Annealed tool steel or other high-carbon or dense alloy steels, and cast iron, should be cut at 75–90 strokes per min.

Unannealed tool steel and noncorrosive steel may have to be cut as low as 50–70 strokes per min.

A copious flow of cutting fluid should be applied to the blade to keep it cool and to wash away the chips when cutting all metals. If high speed steel blades are used, practically all materials may be cut at the maximum speed of the saw or approximately 135 strokes per min.

After the cutting speed has been determined, the next question to be solved is the amount of **feed pressure** to use. This, of course, depends upon the type and size of saw blade, the individual machine, and the kind of material to be cut. A pressure should be maintained which will cause the saw to remove a maximum amount of metal per stroke and yet not bow, bend, or otherwise damage the saw. The saw itself should be subjected to a high strain or tension in its frame. A large sectioned saw well supported can, of course, be tensioned much higher than a light saw blade held in a light frame. It appears to be good practice in securing maximum sawing efficiency to increase the feed pressure as the saw dulls, thereby keeping the cutting time per cut nearly constant and assuring a cutting rather than a rubbing action along the blade edge.

The soft-back saw cannot stand the high feeding pressures that the all-hard blade will, and consequently it does not cut as fast. Neither is its life prolonged by light cutting, although it does resist breakage more effectively. All-hard blades operated at higher pressures are, therefore, preferred. It is better to feed a saw with too much pressure than too little, as the cutting time will be reduced. The saw should be removed as soon as the cutting time begins to increase rapidly. Too little pressure is not economical, as the cutting time is much greater and the blade life is not increased proportionately. Maximum efficiency is to be found in the saw that **cuts quickest and lasts longest.**

The **feed pressure** naturally is dependent upon the kind and size of material being cut and the size and rigidity of the saw blade used. The feed pressure on gravity machines may run from 10 to 50 lb, with added weights, 100 lb. In the spring-tension machines, 175 lb may be obtained. In the positive feed machines, the pressure may reach 300 lb, which is desired for 6-in.-diam. stock. As the work diameter is increased to 9 in., the pressure should be reduced to 250 lb, and for 12 in. diam. to 175 lb so as to allow for chip space. Smaller diameters require lower pressures because of the concentrated load.

Band Saws

Band saws may be made of all-hard steel strip or of hardened teeth with a flexible back. The teeth of the **flexible back** are hardened only to their base to insure them against cracking or breaking while in operation. They need no filing but will cut until worn dull, when they can be replaced at very small cost or discarded. The **all-hard saw** may be resharpened and reset a number of times before being discarded. These saws are made endless by welding the two ends of a long strip together. The teeth of all saws are **set** with the regular **alternate teeth,** one bent to the right and the next to the left, or with the **alternate and center set** in which one tooth is bent to the right, the second to the left, and the third straight in the center. The fine-tooth saws are set wavy. The set is to provide clearance on the side of the saw blade. The teeth are milled and vary from 8 to 32 to the in. for narrow saws, to as few as 3 or 4 per in. for saws 1–1¼ in. wide. Razor-edge sharpness with scalloped edge has been found to be of more benefit than tooth setting when sawing plastics having an abrasive filler and resilient materials.

Metal-cutting band saws are made in sizes ranging from $\frac{3}{16}$ in. wide by 0.025 in. thick, having 32 teeth per in., for which the kerf is about 0.036 in., to saws 1 in. wide, 0.036 in. thick, having 8 teeth per in., and a kerf of about 0.059 in.

In **friction band sawing,** a machine of the type shown in Fig. 7 with speeds ranging from 5,000 to 20,000 fpm is very satisfactory in cutting metals up to ½-in. thickness, employing feeds of 15–20 in. per min. An advantage of this saw is that, as the blade becomes dull, the heat is generated more rapidly and the feed can be increased.

Band-saw speeds: The general practice shows that the harder the material to be cut the slower should be the speed of the blade in feet per minute. The speed range for cutting metals with tungsten-steel saw blades should be somewhat as follows:

Annealed steel and cast iron	100 fpm	feed 1 –1½ in. per min	14 teeth
Soft steel	150 "	" 1½–2 " " "	10 "
Hard bronze	250 "	" 2 " " "	10–14 "
Brass, fiber	300 "	" 2 –3 " " "	14 "
Thin sheets, pipe, tubes	300 "	" 2 –4 " " "	18–24 "

The heavier the section of metal being cut, the heavier the saw should be.

The speed range for soft metals, however, is very great, depending upon the machine and saw used, and ranges from approximately 1,000 fpm in brass foundries to 4,500 fpm and even more for cutting aluminum and magnesium castings, plastics, and wood.

Some performance data based on the Buttress or Skip-Tooth thread of coarse pitch, the standard pitch, and the spring-temper saws show that the coarse-tooth Buttress saw is the most economical. These values are shown in Table 1.

TABLE 1. COMPARATIVE DATA FOR THREE DIFFERENT BAND SAWS WHEN SAWING STEEL*

Saw Data	Type of Saw Tested		
	Special Course Pitch	Standard Pitch	Spring Tempered
1. Saw pitch	3 teeth per inch	6 teeth per inch	4 teeth per inch
2. Average cutting rate, sq in./min	365	240	260
3. Total time to cut 48,300 sq in.	2.0 hr	3.37 hr	3.1 hr
4. Initial cost (½" band, 15'0" long)	$1.72	$1.72	$2.06
5. Resharpening and resetting	None	None	$2.80 (4 resharp) (2 reset)
6. Labor to remove, replace, adjust	None	None	$0.25 (4 changes)
7. Shop burden, 40% of No. 6	None	None	$0.10
8. Productive labor cost at $1.00 hr	$2.00	$3.37	$3.10
9. Shop Burden, 40% of No. 8	$0.80	$1.35	$1.24
10. Total cost to cut 48,300 sq in. (not including overhead)	$4.52	$6.44	$9.55

* Courtesy H. J. Chamberland, The DoAll Co.

Disk or Circular Saws

Disk saws are of three general types:

1. Cold saws, those with teeth which cut at normal cutting speeds, like a milling cutter.
2. Abrasive saws, thin wheels of bonded abrasives which cut at high speed.
3. Friction saws, disks of thin steel with or without teeth which melt the metal by virtue of very high surface speed of the cutter.

Cold saws: The Simonds Saw and Steel Co. manufactures as a standard product metal-cutting saws from 2½ to 60 in. diam., although special ones are made as large as 110 in. diam. Carbon steel, semi-high speed steel, and high speed steel are used in making solid saws. Saws up to 8 in. diam. are often called **metal-slitting saws,** while those 9 in. and over are called **cold metal saws.** The larger saws for metal cutting often are provided with inserted teeth or blades of carbon, high speed steel, Fig. 17, or with blades tipped with sintered tungsten carbide, Fig. 18. An inserted-tooth saw will outlive a number of solid-tooth saws because the teeth can be replaced readily when broken or worn out. The Simonds Saw and Steel Co. recommends inserted blades of high speed steel instead of solid high speed steel saws when the kerf is over $\frac{5}{32}$ in. or the diameter over 16 in., or instead of solid carbon-steel saws over $\frac{7}{32}$-in. kerf or over 26 in. diam. For years, steel disks with diamonds inserted in the periphery have been used for cutting hard minerals and metals.

The **thickness** of metal-cutting saws may vary from $\frac{1}{32}$ to $\frac{1}{2}$ in., depending on the size of the saw and the purpose for which it is to be used.

Several **types of teeth** are used on large circular saws. The teeth for wood saws usually have considerable **rake** and **relief.** The tooth of the solid disk saw must be **offset** so that a kerf or slot is cut wider than the thickness of the disk to prevent rubbing and binding. One tooth may be offset to one side and the next tooth offset to the other side, or the tooth may be swaged, as shown in Fig. 18 as *FF*, in which the point of each tooth is spread an equal amount on both sides of the saw. The offset teeth may be given side rake which is desirable, particularly when cutting with the grain of lumber or in deep slots.

Concave ground saws, or saws with widened inserted teeth, usually are employed for metal cutting. The tooth is wider at the top than the thickness of the disk. Teeth for metal cutting are shorter, have less rake and less relief, and are more rigidly supported than the wood-saw teeth, in order to withstand the greater pressures encountered.

Various **shapes of teeth** used on circular saws for metal are shown in Fig. 14. The alternate **beveled tooth** *C* commonly is used on small metal-slitting saws and by a number of manufacturers of cold-saw metal-cutoff machines on saws of 10–36 in. diam. Every other tooth is ground with a 45-deg bevel on each side to leave a small flat in the center on the periphery. The next tooth is plain. The face of these teeth may be ground radially or with a 10- or 12-deg rake. The alternate beveling distributes the cut per tooth and breaks up the chips. These teeth are used principally for cutting soft spongy metal, such as copper, brass, and bronze, and for deep sawing. The large fillet radius between the teeth prevents the chips from clogging. The beveling at *D* and *E* leaves an overlapping flat on the periphery, and also breaks up the chips and permits heavy feeds and thicker chips with less net power and friction.

The Cochrane-Bly, the Higley, and the Knowlton sawing machines also use a saw, every other tooth of which is 0.012 in. high. These high teeth are beveled on both sides while the short teeth are square. **Alternate notches** on square teeth are one of the tooth forms used to break each chip into two parts, which allows contraction in the cut, thereby

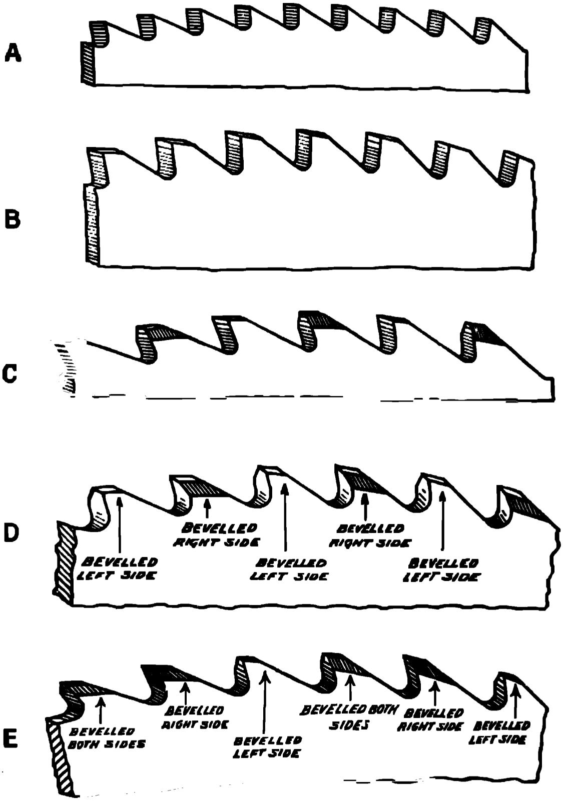


Fig. 14. Various Shapes of Teeth Used on Circular Metal Saws.

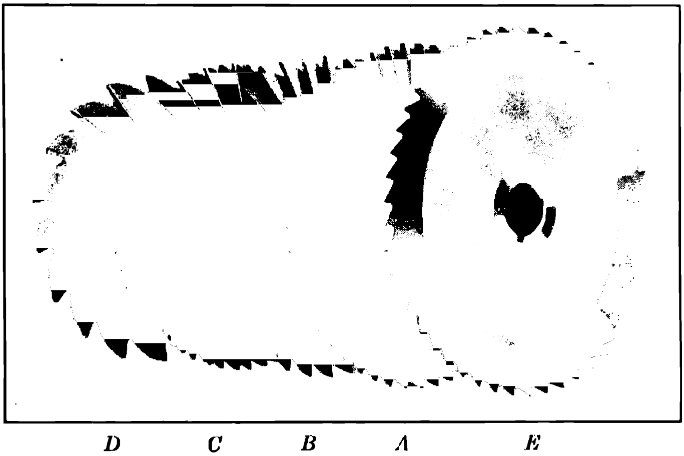
A. Radial teeth for small, fine-tooth saws less than ⅛-in. pitch, for metal slitting or for slotting screw heads.
B. Regular saw teeth with a land for fine-tooth saws.
C. The alternate beveled tooth for cutting soft spongy metal such as copper, brass, and bronze.
D. Alternate side beveled teeth. One tooth is beveled on the right and the next on the left.
E. The Simonds patented teeth has one tooth beveled on the right, the next on the left, and the third beveled on both sides.

reducing friction between the chip and the sides of the wall. This also prevents the chips from clogging in the saw teeth.

A coarse-tooth saw on soft and annealed steels cuts more freely than a fine-tooth saw because each tooth takes a larger chip. In using coarse teeth where possible, less friction is generated, leaving the saw much cooler and allowing it to do more work between sharpenings.

Coarse teeth are stronger than fine teeth and allow more room in the gullets for chips.

The **metal-slitting saws,** Fig. 15, are made in sizes from 3 to 12 in. in diam. of High speed steel for use in standard milling machines. They have a double concave or dished side at the periphery of the saw. The hubs are as thick as the teeth and thicker than the web. A flat bearing is obtained between the arbor and collars as shown in Fig. 16. Such cutters should be keyed to the arbor with a key of sufficient length to extend through the keyway of the cutter well into the keyway of the collar on either side. These cutters provide increased side clearance, maximum bearing on the arbor, full support from the collars, and increased strength of web. Very thin plain cutters, such as type *E*, often are made of sheet steel and are slightly hollow ground for side clearance. Sometimes they are driven by friction between the collars on the arbor, as only light cuts can be made.



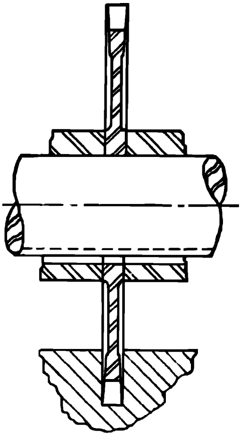
Courtesy Goddard and Goddard Co.

FIG. 15. A Set of Metal-Slitting Saws.

_D_ is a coarse-tooth high-rake cutter with side-chip clearance for copper, aluminum, Bakelite, etc.
_C_ is an alternate-tooth saw for heavy-service cutting steel.
_B_ is a metal-slitting saw with side-chip clearance for cutting steel.
_A_ is a side-chip-clearance saw for cutting cast iron.
_E_ is a standard plain metal-slitting saw for shallow cuts.

Style *A* cutter represents a side-chip-clearance saw for cutting cast iron. Shallow clearance spaces are provided on the sides of the rim back of the radial cutting edge to provide scavenger recesses which keep the slot in the work clean and free from fine chips. These saws are reported to last from two to three times as long as the plain type. This cutter is of medium pitch and is suitable for cutting off or slitting cast iron of any thickness to the hub of the saw and for cuts of moderate depth in steel. It has a rake angle of only 3–4 deg. The proper cutting speed for these saws in cast iron is from 70 to 90 fpm peripheral speed with a feed from 3 to 6 in. per min, depending upon the depth of cut and properties of the metal being cut.

The metal-slitting saw, *B*, Fig. 15, is for cutting steel. This cutter has a rake angle of approximately 10 deg and a pitch slightly greater than that of cutter type *A*. The hub is reinforced to provide an increased bearing on the arbor, greater rigidity, and more pressure area for the key. When cutting mild steel with this saw, a suitable peripheral speed is about 125 fpm with a table feed of 6–8 in. per min, depending on conditions. For the cutting of hard alloy steels, the peripheral speed should be as low as 60 fpm, and the table feed from ¾ to 2 in. per min. These extremes include a wide range of adjustments, depending upon the nature of the material being cut and the size of the cut. When cutting brass with this cutter, the cutting speed may be up to 400 fpm and the feed 10–12 in. per min, or even more. It is not feasible to make these side-chip-clearance saws, either style *A* or *B*, thinner than ⅛ in., as the web between the teeth becomes too thin and frail.



Courtesy Goddard and Goddard Co.

FIG. 16. A Sectional View of a Metal-Slitting Saw Properly Located on an Arbor.

This shows the support between the arbor and the saw and the collars and the sides of the hub. The ample relief on the radial cutting edge of the tooth, at the side of the web, and on the sides of the teeth is indicated.

When a saw having a thickness of ¼ in. or greater can be used, an alternate-tooth milling cutter, *C*, is indicated. These saws are free cutting and will stand heavier feeds than either type *A* or *B*. Alternate shear or side rake may be provided on the periphery, and greater chip space is available on the sides. These saws should be made with reinforced hubs to give suitable strength for driving them.

The metal-slitting saw, *D*, having a 13-deg rake and coarse pitch with increased relief, is used for cutting copper, aluminum, Bakelite, Micarta, etc. The large fillet at the bottom of the tooth and the face of the tooth are highly polished to allow the ribbon chip to slide easily over the face of the tooth rather than wedge against the fillet.

For cutting copper, a surface or peripheral speed of 150–300 fpm with a table feed of 12–20 in. per min is suitable depending upon the conditions, such as the size of the work, its rigidity, and depth of cut. For cutting aluminum, a peripheral speed up to 1,000 fpm may be used with a table feed of 12–20 in. per min. For both copper and aluminum, a suitable cutting fluid should be used, such as a light oil for copper, and kerosene or an emulsion containing kerosene for aluminum.

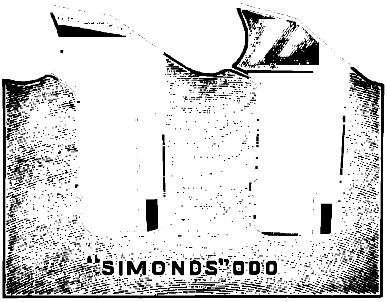


Fig. 17. The Simonds Inserted Blade of High Speed Steel for Circular Saws, Made in Six Sizes.

Every other tooth is rounded on top and is narrower and slightly longer than the alternate teeth, which are flat on top. The high teeth cut a groove in the center of the kerf, and the alternate square teeth cut out the two corners, thus breaking the chip into three pieces. The curved throat of the tooth for bending the chip is clearly shown.

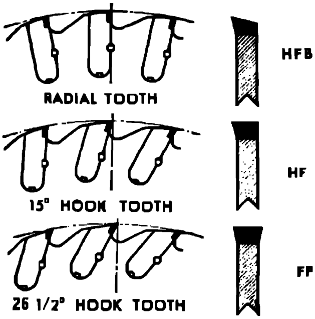


Fig. 18. The Disston Carboloy-Tipped Blades for Circular Saws.

These show the radial, 15-deg hook, and 26½-deg hook angles, as well as the three styles of teeth used in cutting a variety of nonmetallic materials. FF, full formed; HF, half formed; HFB, half-formed bevel.

Inserted blades of high speed steel are shown in Fig. 17. These are in use in Fig. 10. They are ground with a 10–15-deg rake angle and a 12-deg relief angle. The straight face of about $\frac{5}{32}$ in. merges with the gullet of large radius. These teeth dull by abrasion on the land. To sharpen, the face or land or both may be ground.

Inserted blades tipped with **sintered carbide**, Fig. 18, are made in a wide range of sizes from 6 to 30 in. diam. for sawing nonmetallic materials. Fewer teeth than normal are provided as the cutters operate at very high speeds, as 6,500 fpm for asphaltum-bonded flooring and Transite board; 10,000 fpm for Bakelite, cork, hard fiber, gypsum board, Micarta, and plastics; and 16,000 fpm for Celotex, hardwoods, and glued plywoods.

Abrasive disks are made from silicon carbide and aluminum oxide abrasives. Silicon carbide is used principally for cutting cast iron, nonferrous metals, and sintered tungsten carbide; aluminum oxide is used generally for cutting steel. Most of these wheels are made up with a resinoid bond for the abrasive particles. Vulcanized rubber is used as a bond to some extent.

High-speed sawing with rubber- or resinoid-bonded abrasive wheels of 1/16-, 3/32-, or ⅛-in. thickness causes wheels to cut faster, producing more cuts per wheel, and the quality of the cut is improved. For general work on all metals an A30–S7 or A36–T8 wheel is best for maximum wheel life. When a burr is not objectionable, an A46–R8 wheel gives a better quality of cut but lower production, and an A70–R8 wheel gives the best quality of finish. Typical production with rubber-bonded abrasive wheels is as follows:

(*a*) Two-inch-diameter aluminum gates and risers are cut off in 20 sec per piece with 150 cuts per wheel.

(*b*) Two-inch-diameter bronze gates and risers are cut in 30 sec with 80 cuts per wheel.

(*c*) Cold-drawn steel 1 in. diam. is cut in 2 sec with 150 cuts per wheel.

(*d*) A 1½ × 1½ × ⅛-in. steel angle is cut in 3 sec with 85 cuts per wheel.

These wheels are run safely up to 16,000 surface fpm and are used principally for cutting small bar stock, such as tool steel, cold-rolled steel, stainless steel, Stellite rods, tubing, or spring stock. They cut without burring or burning the stock. The saw shown in Fig. 11 uses abrasive disks interchangeably with the steel friction saws.

Noeflex reinforced resinoid cutoff wheels 14, 16, and 20 in. in diam. and 5/32 and 3/16 in. thick with a marking of A241–014BN are now used with great success for cutting gates and risers on nonferrous castings with considerably less wheel breakage than occurs with rubber- and resinoid-bonded wheels. They are also used successfully for cutting off steel.

Friction disk saws are made of a special grade of alloy steel carefully balanced, properly tensioned, and hollow ground with teeth hobbed in the edge to increase the friction.

The teeth are formed by hobbing V or square notches equal approximately in width and depth to the thickness of the saw about the periphery. The teeth on the friction saw used for cutting rails, structural steel, billets, bars, etc., cold or red hot as they come from the mill rolls on their final pass are nothing more than V-type teeth. These friction saws are made in diameters ranging from 14 in. with a thickness of ⅛ in., to 60 in. with a thickness of ⅜ in., and are run at peripheral speeds of 18,000–20,000 fpm. The teeth are hollow ground on the side for clearance and balancing. Hollow-ground saws should be used with 4–8 teeth per in., operating at high speeds of 500–15,000 fpm. An air blast is helpful in preventing the chips from sticking to the saw.

Sawing Various Materials

In cutting **soft metals,** there is a tendency for the chip space to become clogged and filled, causing the saw to rub instead of producing clean-cut chips. This produces excessive heat, causing the blade to soften and wear more quickly.

In sawing **cast plastics,** any **hack saw** or **band saw** may be used, but a thin high-speed abrasive disk is most economical. For average work a band saw should have 14 teeth to the in., and the surface speed should be 1,300 fpm or more. The saw should be ½ in. wide and just soft enough to file. A good saw will run 8–15 hr before requiring resharpening. Band saws of razor-edge sharpness with scalloped edges work well at high speed on resilient materials and soft rubber, cork, etc.

For sawing **stainless steels,** high speed steel blades are recommended. The saw teeth should start cutting with a minimum preliminary rubbing because of the propensity of the metal to harden upon being cold worked. Teeth having a large rake are most desirable, and saw blades with the wavy set have shown excellent performance. **Band saws** serve best for sawing stainless steel on account of the continuous cutting.

A **production hack saw** will cut off a 1½-in.-diam. rod of SAE 1020 steel at the rate of 75 cuts per hr. A total of 7,500 pieces was cut in 100 hr with one high speed steel blade. An emulsion of 1 to 10 was used.

The **positive screw-feed production hack saw** will cut a 5-in.-diam. bar of SAE 1137 steel in 4 min. A total of 176 cuts was obtained with one high speed steel blade when using an emulsion of 1 to 30. The saw with 4 teeth per in. made 135 strokes per min with a feed of 0.009 in. per stroke. With the Cobly **cold-sawing** machine, Fig. 10, a bundle of 26 cold-finished bars 1 in. in diam. was cut off with a **circular saw,** having inserted blades of high speed steel ground to 20-deg rake and 5-deg relief, in 55 sec. The feed was 6½ in. per min. The cutting speed was 75 fpm, and about 200 cuts were made before it was necessary to resharpen the saw blade.

Cutting fluids have a marked influence on the performance of a hack saw. The results of a series of tests (*Trans. ASME*, July, 1934, p. 527) show the influence of cutting fluids when cutting various metals, Fig. 19. The cutting conditions are outlined in the title of the figure. Each point represents an average of the first three cuts of each material. In cutting brass, as well as some of the other metals, the first cut in each case was much lower than the second and third, which were in close agreement. A new high speed steel saw blade was used for each cutting fluid, while one cut was taken on each of the eight bars. A second and then a third series of cuts were taken on the various bars for each oil but in a different order each time.

Dry cutting, No. 1, requires the greatest time for all materials. The water compounds, Nos. 2, 3, and 4, give nearly equal values slightly lower than dry cutting for all the metals. The two sulphurized oils, Nos. 10 and 11, cause the saw to cut fastest. In many of the cases, there is not a great deal of difference between the time values resulting when an oil is used and when cutting dry. It does appear, however, that oil No. 8, consisting of 10 per cent No. 1 lard oil in a light mineral oil, is best for all metals excepting cast iron and brass.

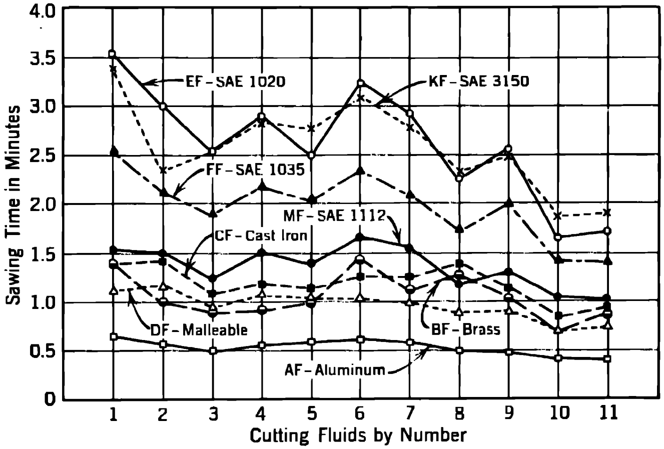


FIG. 19. The Time in Minutes Required to Cut Off a 1½-in.-sq. Section of Eight Different Metals Is Given When Cutting with Various Cutting Fluids.

A Peerless high-speed standard-type hack-saw machine having a 9 × 9 in. capacity, as shown in Fig. 2, was used when making 120 strokes per min with a feed pressure of about 119 lb. A No. 852 Starrett high speed steel saw blade 17 in. long, 1 in. wide, and 0.065 in. thick was used. It had 6 teeth per in. and produced a kerf of 0.082 in. The set of the teeth was right, left, two straight, etc. The experimental values are the average of the first three cuts of each material. The cutting fluids used were as follows:

1. Dry cutting.
2. Water containing 1½ per cent borax.
3. 1 part soluble oil to 50 parts water.
4. 1 part soluble oil to 10 parts water.
5. A No. 2 lard oil.
6. A light mineral oil.
7. A heavy mineral oil.
8. A light mineral oil containing 10 per cent lard oil.
9. A light mineral oil containing 5 per cent oleic acid.
10. A sulphurized mineral oil.
11. A sulphurized lard-mineral oil.

The 119-lb feed pressure is prorated over 9 teeth in contact with the work. This amounts to 13.22 lb per tooth. In similar tests in a 6 × 6-in.-capacity saw of the same type as that used in the tests mentioned above, a saw blade having 10 teeth per in. was used when making 90 strokes per min. The total feeding pressure was 131.2 lb, which was distributed over 15 teeth in contact with the work, resulting in a feeding pressure per tooth of 8.75 lb. The cutting time for the same materials as mentioned above with the same cutting fluids for the 10-tooth-per-in. saw blade for cutting aluminum dry, cutting fluid No. 1, was 1.4 min as compared with 0.65 min for the 6-tooth-per-in. saw. The corresponding times when cutting SAE 3150 steel was 6.5 min for the 10-tooth-per-in. saw as compared with 3.4 min for the 6-tooth saw. This indicates that the cutting time was practically doubled.

When cutting the SAE 1112 steel, it was found that the dulling effect on a saw blade, as indicated by increased cutting time, varies with the type of cutting fluid used. The dulling of the high speed steel saw blade having 6 teeth per in. was found to be very little when the emulsion No. 3 was used. After cutting 70 1½-in.-sq sections (157½ sq in.), the time was increased from 1.3 min to about 1.45 min. The saw blade showed slight signs of wear. When using the tungsten blades ¾ in. wide by 0.049-in. gage, 12 in. long, with 14 teeth per in. on the same steel, the wear was found to be appreciable in cutting off 70 sections. The time of the first cut was almost doubled for the last cut when using each of four cutting fluids.

Cutting Fluid	*Time, First Cut*	*Time, Seventieth Cut*
6	2.0	3.0
8	1.5	3.6
3	1.7	2.4
10	1.5	2.1

This shows that No. 10 sulphurized oil causes the least time for any cut. Emulsion No. 3 is a close second as to time, but the blade was practically ruined, whereas that on which No. 10 was used showed but little wear.

QUESTIONS

1. What are the three principal types of sawing machines?
2. What are the three principal classes of circular sawing machines?
3. What is meant by kerf? Explain its relation to the thickness of the saw.
4. What types of materials are used to form the cutting blades of circular cold saws?
5. Of what materials are hack saws made?
6. What types of material are cut with circular saws with blades tipped with sintered carbide?
7. What is meant by the set of a saw?
8. When are hack-saw blades with fine teeth used?
9. When are hack-saw blades with coarse teeth used?
10. In what ways is the feeding pressure on a hack-saw blade obtained?

11. What are the advantages of the soft-back blade as compared with the all-hard blade?

12. What are the advantage and purpose of the cutting fluid in machine hack sawing?

13. Fully describe the hack-saw blade, the cutting speed, and cutting fluid you would use in cutting off sections of cast aluminum 2 in. sq.

14. What is friction sawing, and how is it applied to band and circular sawing?

15. In sawing off a 6-in.-diam. bar of cast iron in a hack saw, state the following: the number of teeth per inch, the feeding load, the load per tooth, the cutting speed in strokes per minute, and the time required to separate the piece if high speed steel blades are used.

16. Repeat the values of problem 15 if ½-in.-diam. steel bars are to be cut off.

17. Explain the difference between cold sawing, abrasive sawing, and friction sawing as applied to circular saws.

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CHAPTER X

DRILLING, BORING, REAMING, AND THREADING

The subjects of drilling, boring, reaming, and threading, as applied principally to drill presses or specialized machines, are grouped together, inasmuch as the four operations may be done separately or collectively in any combination on many machines of the same type. A machine designed primarily for drilling may be used to advantage also for boring or reaming simply by changing the cutting tool. With possible slight modifications or by the use of attachments, this same machine may be used for threading.

DRILLING MACHINES

A drilling machine or drill press, as it often is called, is designed to hold the drill or cutting tool and provide a means for furnishing the proper rotating speed and axial feed. The **size** of many drill presses may be expressed by the diameter in inches of a disk, the center of which can be drilled. This size corresponds to the swing over the ways of an engine lathe.

Classification of Drilling Machines

Drilling machines are made in many different types and sizes, each designed to handle a class of work or specific job to the best advantage. The complete classification of any drill press is involved, consisting of many features based on design or construction, purpose, and application of power, as follows:

Features of Design or Construction

Portable, Fig. 1, or stationary, Fig. 2.
Bench, Fig. 2, or floor mounting, Fig. 3.
Round column, Fig. 3, or box column, Fig. 4.
Horizontal, Fig. 12, or vertical (upright), Fig. 3.
Light duty, Fig. 4, or heavy duty, Fig. 6.
Fixed-position spindle, Fig. 6, or radially adjustable spindle, Fig. 14.
Fixed head or spindle support, Fig. 6, or sliding head, Fig. 4.
Table feed or spindle feed, Fig. 2.
Adjustable table, Fig. 3, or fixed table, Fig. 10.
Single spindle, Fig. 2, or multiple-gang spindle, Fig. 8, and multiple-cluster spindle, Fig. 9.

Multiple spindle, horizontal, Fig. 12; vertical, Fig. 10; horizontal and vertical, Fig. 11.
Single way, Fig. 10, or multiple way, Fig. 11.
With threading (spindle-reversing) attachment or without.

Application of Power

Hand or power driven.
Belted from shaft, Fig. 3, or self-contained motor drive, Fig. 6.
Sensitive or hand feed, Fig. 2, or power feed, Fig. 3.
Mechanical feed (rack and pinion, etc.), Fig. 5; lead screw or cam, Fig. 11, and hydraulic feed, Fig. 12.
Manual, Fig. 3, or semiautomatic, Fig. 11.

Purpose

General use, Fig. 6, or single purpose, Fig. 10.
Low speed, Fig. 3, or high speed, Fig. 4.
Drilling and boring, Fig. 10, center drilling, or tapping.
Special manufacturing, Fig. 7.

Portable drills are made in a large variety of types and sizes. They are sometimes mounted on a bench stand or post bracket in garages or small job shops for use as fixed single-spindle drill presses. A portable type of electric motor drill, Fig. 1, is a powerful ball-bearing drill of rugged contruction. It is well balanced and easily handled and has a wide range of usefulness. The universal motor operates on direct or alternating current. It is equipped with ball bearings on the armature

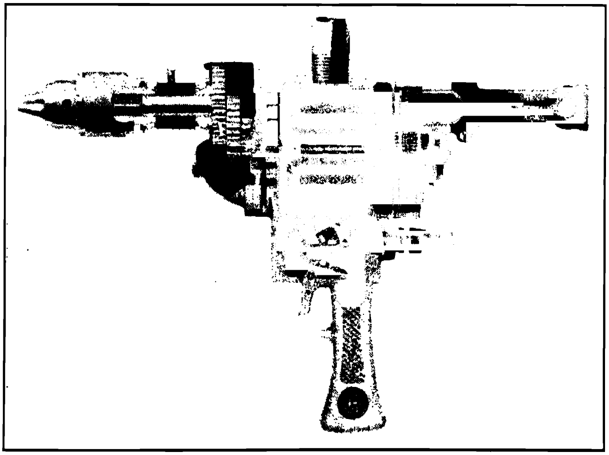


Fig. 1. A Sectional View of the United States Electrical Tool Company's Heavy-Duty Ball-Bearing Universal Motor Portable Drill.

This drill is made with a capacity of a $\frac{3}{8}$-in.-diam. drill in steel at a speed of 750 rpm.

and Timken radial thrust bearings on the chuck spindle. The gears are of hardened chrome-nickel-alloy steel and run in a greasetight gear case. A quick make-and-break trigger switch is provided. This drill is made weighing 14 lb for driving a ⅜-in.-diam. drill in steel at 750 rpm. Smaller and larger drills with appropriate speeds are available.

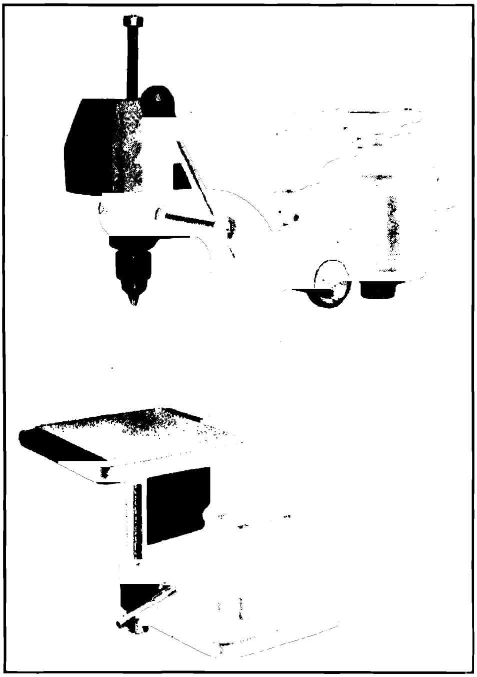


FIG. 2. The Buffalo Forge Co. 10-in. Heavy-Duty Production-Type Sensitive Bench Drill Press.

A ¼-hp, 1,800-rpm, vertical ball-bearing motor of the high-starting-torque type drives the spindle by means of perfectly balanced three-step die-cast pulleys and V belt, providing three spindle speeds of 850, 1,750, and 3,000 rpm. The height of the drill is 32 in.; its capacity is ½-in.-diam. drill in cast iron. It is furnished with a No. 6A Jacobs chuck. The distance from the column to the center of the drill is 5⅛ in. The spindle travel is 3½ in.; maximum distance from chuck to table, 11½ in.; and vertical movement of adjustable table, 10 in.

Bench-type drills, Fig. 2, are usually made for drilling light work with small drills. This is a **sensitive feed** press, as the spindle is fed downward by the feeding handle by hand so that the resistance encountered by the drill can be felt by the operator. A coil spring on the left end of the feeding spindle counterbalances the spindle and causes it to return to its highest point when the feeding handle is released. The knurled wheel on the horizontal screw drives a rack which adjusts the motor to or from the spindle for keeping the Dayton-Cog V belt at the correct tension. It is locked in position by the knurled wheel on the vertical setscrew. The starting and stopping switch lever is attached to the motor.

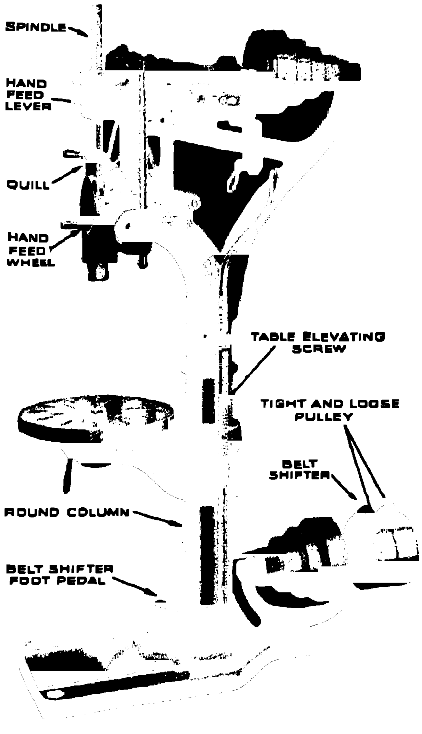


FIG. 3. The Old Type W. F. and John Barnes No. 146 20-in. Single-Spindle Drill Press.

It is provided with a square base, back gears, and power feed. The round table may be swiveled about its axis and that of the column and may be raised or lowered by the vertical screw. The drive is from a line shaft or motor to the tight and loose pulleys. The belt is shifted from one to the other by the foot pedal. The four-step-cone pulley with single back gears provides eight spindle speeds. The head is fixed and the spindle may be fed by hand directly by the long lever or by the feed wheel through the worm and worm wheel reduction. Power feed through the miter gears and the worm and worm wheel furnishes four feeds of 0.005, 0.007, 0.009, and 0.016 ipr of the spindle.

A simple single-end **centering machine** usually is horizontal with a stationary three-jaw universal chuck, to center and hold the work or bars to be centered, as for mounting on lathe centers, while a rotating center drill and countersink is fed into the work by a handwheel-driven screw.

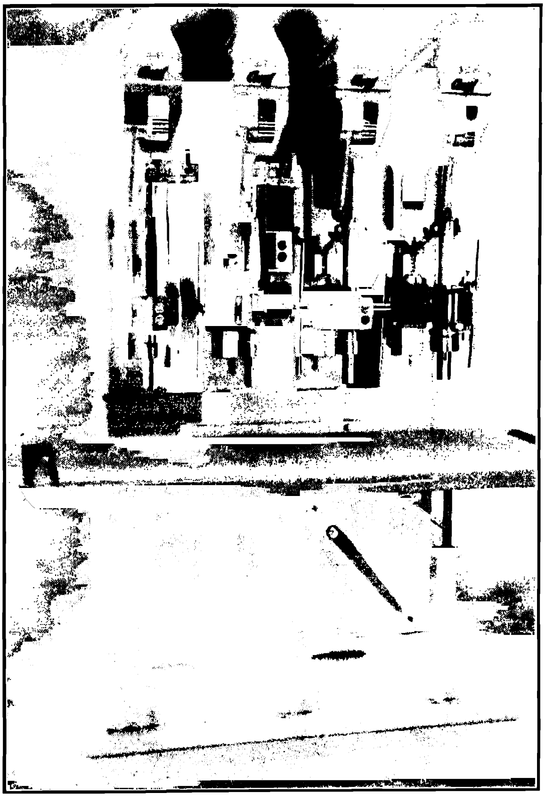
Standard upright drilling machines: The **general-purpose drilling machine,** of the upright type for floor mounting for light or heavy work, usually is provided with a wide range of spindle speeds and feeds. An old type with step-cone-pulley and back-gear drive is shown in Fig. 3. **Power feed** is provided so that the drill can be fed into the work at a uniform and positive rate.

Power may be applied to drill presses in a manner similar to that applied to lathes, shapers, etc. A belt from the countershaft may drive to a step-cone pulley, to a tight and loose pulley, Fig. 3, or to a single-pulley drive operated through a clutch. The more modern method is to have a self-contained motor which drives the spindle directly through a short belt, Fig. 2, or, when arranged for motor drive, drives the single pulley connected to the spindle through change gears, Fig. 6.

The **Avey** box-column, high-speed, motor-driven drill press is shown in Fig. 4. Four columns of the standard single-spindle unit, each individually motor driven, are mounted on a common base to form a four-spindle **gang drill.** The motor, mounted vertically back of the column, drives through a six-speed gearbox. The lever at the upper front of the machine shifts the gears for speed change. The gang drill shown represents the four types of spindle feeds mentioned in the legend. Any of these spindles may be adapted to positive lead screw tapping or for multiple head drilling. The single-spindle units may be equipped with a round table, a large fixed rectangular table, or a smaller compound table with accurate longitudinal and traverse travel. Push-button control is provided on the sliding head of each spindle, and the table may be adjusted vertically by the single crank operating the three vertical screws.

In some drill presses, such as the small Leland-Gifford, the motor armature is mounted directly on the spindle. The motor is wound for four speeds, such as 3,600, 1,800, 1,200 and 900 rpm, so no gear changes are involved. Some drilling machines of this type feed the drill by a **disk cam** rather than by a rack in the quill. The cam is mounted on the pinion-feed shaft of the sliding head and bears against a roller attached to the lower end of the quill. This cam may furnish rapid traverse of drill to work, proper cutting feed, dwell at the end of cut if desired, and rapid return to the starting position. A sectional view of the high-speed Avey spindle for a $\frac{3}{16}$-in.-diam. drill is shown in Fig. 5*A* with that of the Atlas Press Co.'s small drilling machine (5*B*).

The Barnes all-geared, upright drill press shown in Fig. 6 is of the box-column type for job-shop or production work. Greater accuracy may be obtained from the box column because of its rigidity, but greater versatility may be obtained from the round-column type because of the maneuverability of the round table shown in Fig. 3. This machine has six speeds, obtained by the two long levers on the upper right side of the head, from 142 to 1,415 rpm, and six feeds, obtained by the two small levers on the front of the head, of 0.004, 0.006, 0.009, 0.014, 0.021 and 0.031 ipr. The large lever on the left side of the head engages the forward and reverse speed clutches on the back shaft and is used for starting, stopping, or reversing in case of tapping.



Courtesy Avey Drilling Machine Co.

FIG. 4. The Avey Four-Spindle Gang-Type BMA.6 Drilling Machine.

Each column consists of a motor and gearbox which provides six spindle speeds up to 4,800 rpm and four feeds of 0.003, 0.006, 0.009 and 0.012 ipr. The machine shows four types of spindles. No. 1 at the left is the Avey-matic feed for full automatic or semiautomatic cycling, No. 2 has the plain power-feed unit, and No. 3 has the hand-feed unit, while No. 4 has the tapping attachment for reversing the spindle by reversing the motor, which is then stopped by a solenoid brake.

The feed is disengaged and the spindle stopped if the stop near the fulcrum of the start lever is vertical as shown, but the spindle will reverse to withdraw tap if this stop is placed horizontally so the lever can rise higher to engage the reversing clutch. The 3-hp constant-speed motor is located in the box column and drives by silent chain

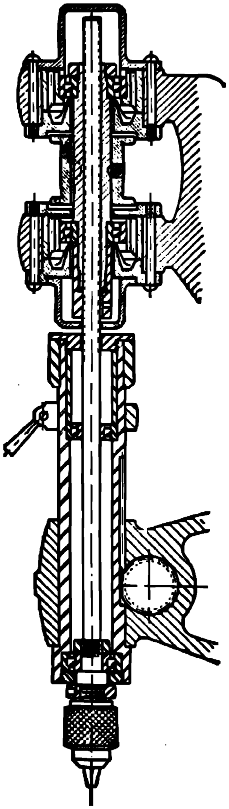


FIG. 5*A*. A Sectional View of the Avey No. ½ Drilling Machine Spindle Designed for High Speed on Light Work.

The spindle is carried entirely in annular ball bearings. This construction permits spindle speeds up to 12,000 rpm. Each of the upper two bearings is of the self-aligning type and is lubricated by flingers which dip into an oil reservoir.

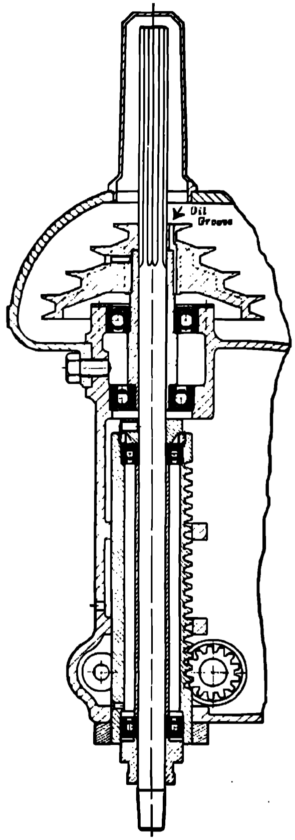
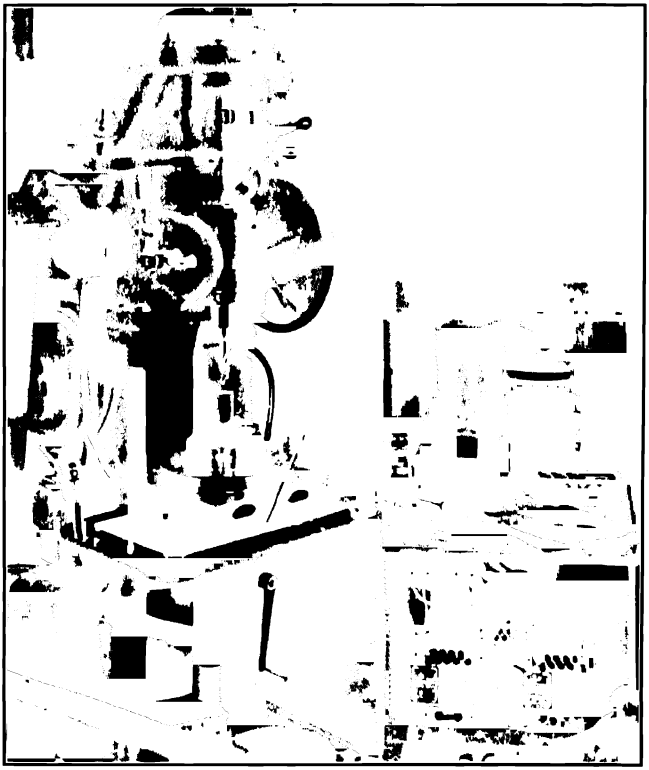


FIG. 5*B*. A Sectional View of the Atlas Press Co.'s Spindle-Head Design for the Small No. 63 Drill Press.

The driving pulley, carried on a sleeve, is 6-splined to the spindle at the top. The drawing shows how the pinion gear meshes with the quill rack teeth for the spindle feed.

to the constant-speed shaft. Push-button control is provided, operating through the reset and knife switch. The fuses are placed in the panel which serves the whole room. The wattmeter is shown plugged into a socket on the left side of the head provided for quick assembly of the portable wattmeter unit. The wattmeter measures the gross,



Courtesy Barnes Drill Co.

FIG. 6. The Barnes 201$\frac{1}{4}$ Self-Oiling, All-Geared, Box Column, Upright Drill Press.

This machine is used in the machinability laboratory for studying metal-cutting and cutting-fluid problems. It is provided with a recording wattmeter and a dynamometer which measures torque and thrust up to the capacity of the machine of driving a 1$\frac{1}{2}$-in.-diam. drill in steel.

tare, and net power developed by the motor. The special dynamometer mounted on the table, using electrolimit units, records the torque and thrust on the cutting tool from which the net power at the cutter can be computed. The spindle is provided with a No. 4 Morse taper and a cylindrical quill, but flanged quills are available for mounting large multiple drilling heads.

Production Drilling Machines

Single-spindle drilling machines are adapted to large production by providing various devices which help to reduce handling and machining time and lead to the economical manufacture of interchangeable parts. These devices provide multiple tooling as with multiple drilling heads, jigs, automatic spindle return, positive tap leads with mechanical or electrical automatic reverse, and dwell attachment to permit the tools to clean up at the end of the cut as in spot-facing. Multiple tooling may be obtained by adding multiple drill heads to a single spindle, adding more spindles, or both. Multiple stations can be provided so that several spindles can operate simultaneously or so that, while one spindle is in action, work previously machined can be replaced by rough stock and then quickly indexed into position. Various kindred operations, such as drilling, boring, counterboring, reaming, facing, and threading, can be performed successively and/or simultaneously.

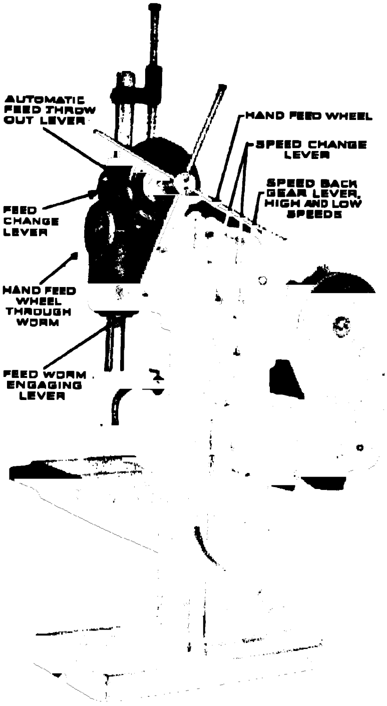

AUTOMATIC FEED THROW OUT LEVER
HAND FEED WHEEL
SPEED CHANGE LEVER
SPEED BACK GEAR LEVER, HIGH AND LOW SPEEDS
FEED CHANGE LEVER
HAND FEED WHEEL THROUGH WORM
FEED WORM ENGAGING LEVER

FIG. 7. The W. F. and John Barnes No. 300 20-in. General-Purpose Production Drill Press.

A 5-hp, 1,200-rpm motor drives directly through silent chain. The machine is equipped with a cutting-fluid pump and piping, with the tank in the base of the column. Rated to pull a 1½-in.-diam. high speed steel drill to its capacity in solid steel. The box-type column is designed for rigidity. The head is fixed, and the spindle is driven through multiple-spline steel shafts. Eight quick-change speeds from 72 to 500 rpm with a drive pulley speed of 500 rpm are obtainable through the three levers on the right-hand side of the column. The feed lever located at the front of the machine gives two quick changes of feed for each pair of pick-off gears. The high feed is three times the low. By transposing the pick-off gears located on the left side of the head, two additional feeds are available. Twenty-four feeds in all, from 0.005 to 0.115 in., may be obtained. The power feed mechanism can be disengaged automatically at any predetermined depth.

The **heavy-duty general-purpose** production drill press, Fig. 7, has eight speeds obtainable through gear trains built into the machine, but only two feeds, one three times the amount of the other, are available for each pair of feed pick-off or transposing gears. These feeds are arranged so that one is fine, such as required for drilling, while the second is coarse, as required in reaming or boring. For each setup, the correct pair of feed pick-off gears is selected. The gears can be replaced if other rates of feed are required. The machine is furnished with direct-motor drive through silent chain or belt. For high production, but one spindle speed is provided for the particular job to be performed, although the two quick-change feeds are retained. A spindle-reversing clutch may be provided in the head for tapping so that the spindle can be driven forward to feed the tap in, and then reversed at a higher speed to back the tap out.

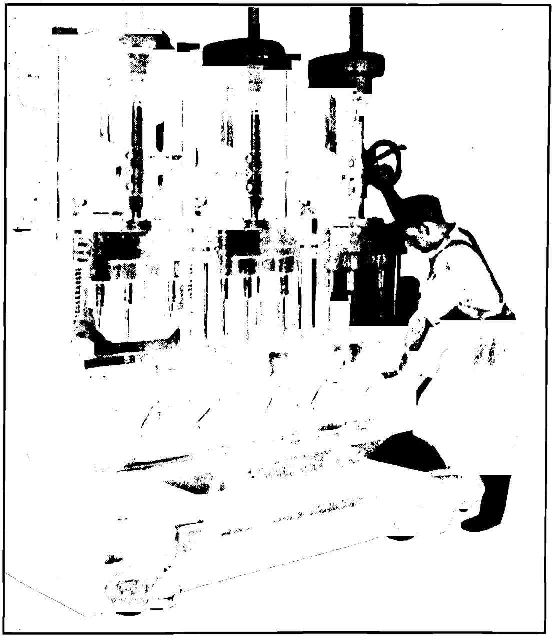


FIG. 8. A Barnes Drill Co. Gang-Type Three-Spindle Production Drilling Machine.

This machine is provided with jigs for progressively machining the cast-iron gear cases for a washing machine. Each quill is provided with a flanged end on which a four-spindle multiple head is mounted. In the jig at the left, the work is drilled; in the center spindle, the bosses are spot-faced; and in the spindle at the right, the holes are reamed.

A **multiple-spindle gang-type** drill press, Fig. 8, consists of three standard spindles and columns mounted on a common base with adjustable table. The spindles of gang drills are often equipped with identical jigs so that one operator can keep several spindles busy on one operation of one part in mass production. In Fig. 8, each spindle is provided with a four-spindle auxiliary head, guide bushing plate, and holding fixtures. A cast-iron gear case is being machined **progressively** from left to right. Four holes are being drilled in the piece at the left. Two $\frac{47}{64}$-in.-diam. high speed steel twist drills are running at 450 rpm with a feed of 0.015 ipr. and two $1\frac{15}{64}$-in.-diam. drills are running at 270 rpm. The work is then moved to the center fixture where the four bosses are spot faced. The spot-facing tools operate at 120 rpm, but the feeding is done by hand. After spot facing, the work is transferred to the jig at the right where the two $\frac{47}{64}$-in.-diam. drilled holes are reamed to 0.750 in. diam. by reamers running at 225 rpm and a feed of 0.023 ipr. The two $1\frac{15}{64}$-in.-diam. holes are reamed to 1.250 in. diam. by reamers running at 150 rpm. Twenty-four complete gear cases are produced per hour by one man.

An **adjustable multiple-spindle cluster-type** vertical drilling machine is shown in Fig. 9. One 30-hp motor drives the single spindle leading to the sliding head which, in turn, distributes power to each of the sixteen spindles. The feeding of the drills and the rapid traverse of the head are controlled by an Oilgear hydraulic pump driven by a 3-hp constant-speed motor. The capacity of this machine is twelve $1\frac{1}{2}$-in.-diam. high speed steel twist drills in cast iron. Any one or all of the spindles may be released from the position shown, and quickly reclamped in any position required by another job. The lower end of each spindle, fixed in any desired location, is driven from the upper fixed portion of the head by a telescoping shaft provided with universal joints at each end. In general-purpose machines of this type, all spindles are rotated at the same speed. For special semiproduction jobs, speed-reducing gears may be attached to the lower end of a shaft so that a drill larger than the others may be operated at its proper peripheral cutting speed.

A single-spindle hydraulically fed boring and facing machine having a multiple head with three spindles and a **three-station indexing fixture** is shown in Fig. 10. A rigid bushing plate is attached to the column immediately over the index table for piloting the various boring and facing bars. The three spindles are driven by the single vertical motor. The motor drives the spindles through two sets of worms and worm gears for reduction, also through spur pick-off gears at the side of the head. These pick-off gears are readily accessible and may be changed with the tools and jig for any other job. The hydraulic feed is obtained through the Oilgear variable-displacement pump driven by a separate motor in conjunction with a cylinder and relief valves. The work is indexed from the loading station, successively, to each of the working spindles.

A special semiautomatic machine for drilling, reaming, counterboring, and tapping various holes in malleable cast-iron steering-gear case is shown in Fig. 11. There are five individual fixtures mounted on an indexing table. Two castings are clamped in each fixture by an equalizing clamp operated by a jig lock through a rack and pinion. The previously finished large flat face is upward and located by dowels in the dowel holes at right angles to the long bore.

FIG. 9. The Special National Automatic Tool Co. Multiple-Spindle Cluster-Type Drilling Machine.

Equipped with a semiautomatic hydraulic Oilgear feed controlled by a single foot lever. This is a multiple-spindle machine of the cluster type having sixteen 3-in. adjustable spindles each having a No. 4 Morse taper. The head is driven by a 30-hp variable-speed motor ranging from 300 to 1,200 rpm. The Oilgear pump shown on the base at the right is driven by a 3-hp constant-speed motor. The track and fixture trucks permit the loading and unloading of large heavy pieces to be drilled, while another piece is being drilled, thereby reducing the idle time of the machine. The weight of the machine complete with 20 ft of track and two fixture trucks is approximately 43,000 lb.

There are three multiple-spindle heads mounted on the vertical column of the machine and two additional units each mounted on a side bracket. These sideheads are individually operated by an automatic drilling and tapping unit. The loading station is in front where all electrical controls are placed, although the machine can be started or stopped from the front or rear, as there are three sets of control buttons conveniently located so the operator can adjust tools in any position. The complete machine is electrically synchronized, making it foolproof so that the automatic rotary table cannot be indexed during any operation. When all units are in the back position, the table is then automatically indexed, after which all units are automatically started on their respective operations.

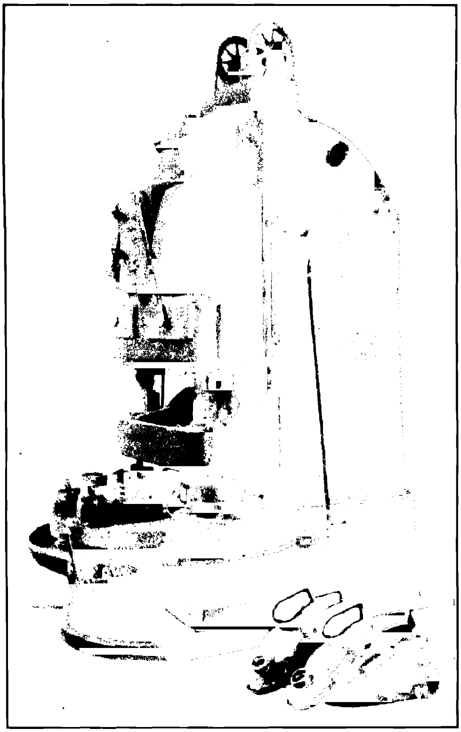


Fig. 10. The Rockford Drilling Machine Co. Vertical-Type Hydraulic Feed Machine.

Arranged with a three-station indexing table for progressive boring operations on a large tractor cast-iron gear-case housing. Unloading and loading take place at the first table station. The hole through the hub is bored and the hub is rough turned, faced, and counterbored at the second station. At the third station the hole in the hub is finish bored and turned, and in addition the large hole in the other end of the case is rough and finish bored. At each indexing of the table a gear-case housing is machined with all the above operations completed.

At the first working station to the left, the large recess in the flat face of the part is counterbored, and one of the sideheads rough-counterbores the long hole in the body. The counterbore is piloted with a roller pilot in the main locating plug. At the second station, five holes are drilled in each part of the vertical head, while the sidehead finish-counterbores the long hole in the body. At the third station, three holes in each part are countersunk and two holes are reamed. At the fourth station, three holes are tapped in each part which finishes the different operations required. Each vertical multiple head is equipped with hardened and ground guide bars piloted in the fixture through hardened and ground bushings. By this method of alignment the positions of the tools are definitely controlled.

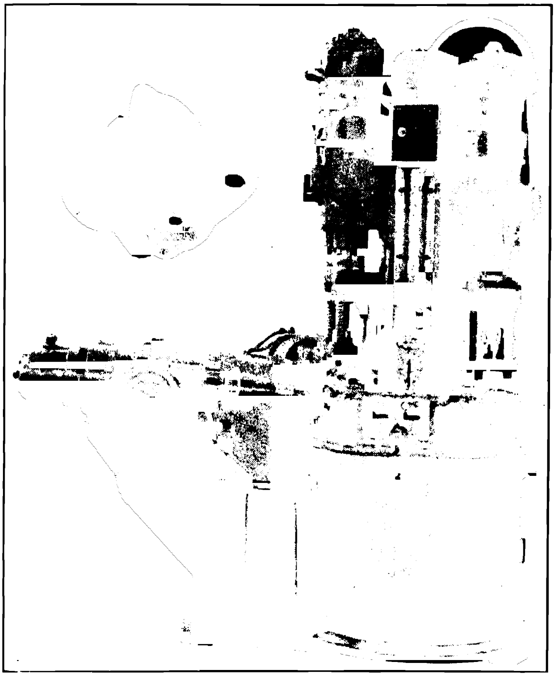


FIG. 11. An Ex-Cell-O Corp. Special Semiautomatic Machine with Indexing Table and Fixtures.

For drilling and reaming two holes; drilling, countersinking, and tapping three holes; counterboring large openings; and rough and finish counterboring the barrel of a malleable cast-iron steering-gear case shown in the insert. The operator is able to load and unload the parts while the machine is in continuous operation.

In machining this malleable cast-iron case, drills were run at a cutting speed of 90 fpm. The reamers operated at a cutting speed of 60 fpm, which is from one-half to three-quarters of the drilling speed. The counterbore speed is 50 fpm, with a standard practice of providing a dwell at the bottom of the stroke so as to clean up the surface. The tapping speed is 40 fpm, which is taken as approximately one-half that of drilling. The feed for the reamers is from three to five times that of the drills of the same size, while the counterbore feed is from 0.004 to 0.006 in. for this particular job. This machine is equipped with cam-fed standard heads.

A two-way horizontal hydraulic-feed 61-spindle drilling machine, Fig. 12, is equipped with two Oilgear pumps and feed cylinders. Both pump units are flanged to the side near the end of the machine base and are driven by motors located on brackets at the ends of the base. These self-contained units are built on flanges suitable for the mounting and consist of the variable-displacement pump and a gear pump for rapid traverse, as well as a small built-in gear pump to maintain the peak pressure on the variable-delivery unit. An internal relief valve limits the peak pressure in the system to protect the pump, work, and tools against overload.

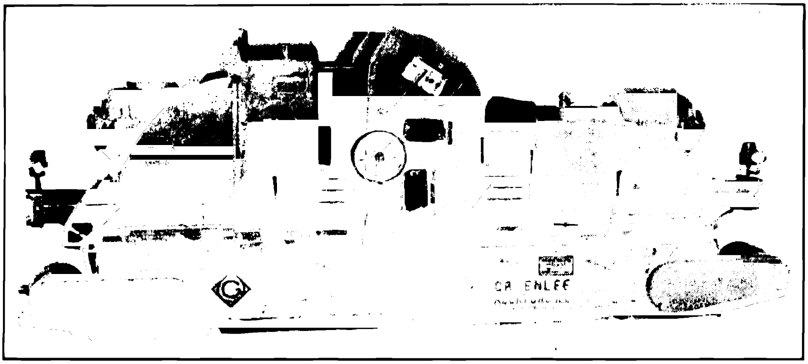


Fig. 12. A Greenlee Brothers and Co. Special Two-Way Horizontal Hydraulic-Feed, Multiple-Spindle, Drilling Machine.

This machine is arranged with a three-stage progressive fixture for drilling and boring a cast-iron cylinder head. At the finish of each cycle with this tool, a completely drilled and bored cylinder head is removed. Sixty-one spindles are employed, and a cylinder head is moved progressively from the lowest to the highest position in the fixture at each pass.

Holes are being drilled and bored in the top, bottom and spark-plug side of a manifold, simultaneously in the three-station progressive jig, as follows:

Top:	20 — 16.5-mm-diam. drills.
	8 — 21.5 " " " for valve bushings.
	2 — $^9/_{16}$ in.-diam. tap drills for 12 threads per in. tap.
Manifold side:	4 — tap drills for $^1/_2$-in.-diam. 12 threads per in. holes.
	2 — 44.5-mm-diam. boring tools for intake portholes.
Spark-plug side:	1 — 8-mm-diam. tap drill for $^3/_8$-in. 16-thread tap.
	4 — 20.5-mm-diam. drills for spark-plug holes.
Bottom:	20 — 16.5-mm-diam. drills.

A four-way hydraulic drilling machine having one vertical and three horizontal heads, Fig. 13, is arranged with the NATCO Hydro Uni-Power system of hydraulic feed which is semiautomatic in operation. The spindles of each head are driven by an individual motor mounted

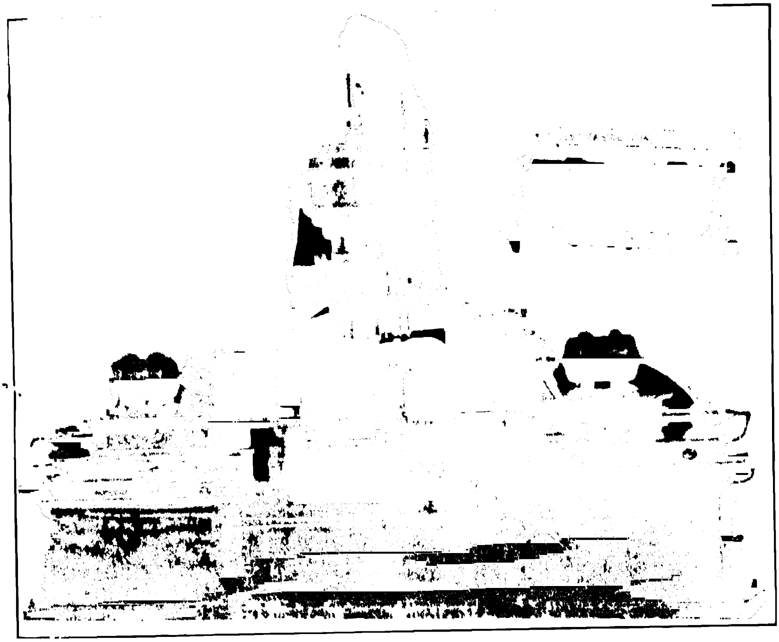


Fig. 13. A National Automatic Tool Co Four-Way Hydraulic Drilling Machine with Trunnion-Type Jig.

The machine is built up of four type-A 1-in standard NATCO hydraulic units with one vertical and three horizontal heads A total of twenty-three spindles is provided A two-position trunnion-type jig is furnished for drilling a cast-iron typewriter frame at the rate of 145 pieces per hr.

on that head. A separate motor in the rear drives the hydraulic pump for furnishing traverse and feeds to the three heads. A **two-position trunnion-type jig** is provided for performing the following operations on a cast-iron typewriter frame about 14 in long and 6 in. wide.

Position No. 1 (as shown)	Load and unload.		
Position No. 2 —	Drill 3 —	0.18-in.-diam.	holes for $^3/_{16}$-in. reamer.
	Drill 3	0.104 "	" 5–40 tap.
Vertical head —	Drill 4 —	0.185 "	" 0.189-in. reamer.
	Drill 1 —	0.1285 "	hole.
	Drill 2 —	0.1695 "	holes.
Right-hand head —	Drill 1 —	0.302-in.-diam. (X drill)	for $^5/_{16}$-in. reamer.
	Drill 1 —	0.104 "	hole for 5–40 tap.
	Drill 1 —	0.1405 "	" 8–32 "
Left-hand head —	Drill 1 -	0.302-in.-diam.	hole for $^5/_{16}$-in. reamer.
	Drill 2 —	0.104 "	" 5–40 tap.
	Drill 1 —	0.1405 "	" 8–32 "
Rear head —	Drill 1 —	0.082-in.-diam.	hole for 3–48 tap.
	Drill 1 —	0.161 "	" 0.166-in. reamer.
	Drill 1 —	0.104 "	" 5–40 tap.

Radial Drilling Machines

The single spindle of a radial drill is mounted in a head which is carried on a horizontal arm. The arm, in turn, is supported and is vertically adjustable on a column about which it swivels. The head may be moved radially on the arm, and the spindle moved vertically in the head.

Radial drills are employed for general utility work. They are rigidly constructed and are provided with a wide range of speeds and power feeds, as they may be used to drive drills ⅛ in. diam. up to 3 or 4 in. diam. as well as large boring tools, taps, etc.

The capacity or size of a radial drill is given as the radius in feet of a disk that can be drilled in its center. The diameter of the column, as well as the radial swing of the head, is important, particularly for heavy-duty work. Some of the smaller machines, such as the American Maxi-Speed Sensitive radial, built with a 9-in.-diam. column in 3-, 3½-, and 4-ft sizes, are provided with a range of six or eight high speeds from 400 to 2,000 rpm, and only three power feeds of 0.003, 0.006, and 0.010 in., as most of the drilling on these machines is done by hand feed. It is intended only for a light high-speed drilling, using drills up to 1 in. diam. in cast iron, or ¾ in. diam. in steel, and has been designed primarily to permit quick handling between drilling operations.

The radial drill, made with a 17-in.-diam. column and an arm length of 5, 6, 7, or 8 ft, is shown in Fig. 14. Fifteen power feeds are provided through the single lever and small dial on the front of the head, ranging from 0.004 to 0.125 ipr of the spindle. This includes five power tap leads for 8, 11½, 14, 18, and 27 threads per in. Twenty-four spindle speeds are available. Four speed changes are available from levers at the left side of the head for each of six speeds available through the two levers on the arm near the column. The speeds are arranged so that there are four distinct ranges for high-speed drilling and light tapping, and for heavy tapping, boring, facing, and trepanning. A tapping attachment through which power is transmitted to the spindle and which is used in starting, stopping, and reversing the spindle is mounted on large thrust and radial ball bearings, and runs in a bath of oil in an oiltight case.

This machine is made in a light size with twelve speeds ranging from 70 to 1,500 rpm, having a 3-ft arm and a 9-in.-diam. column, or in the triple-purpose type with various lengths of arm on columns 11, 13, 15, 17, 19, 22, and 26 in. diam. The longest arm length of this type of radial is 12 ft, with which it is possible to drill in the center of a 24-ft-diam. circle.

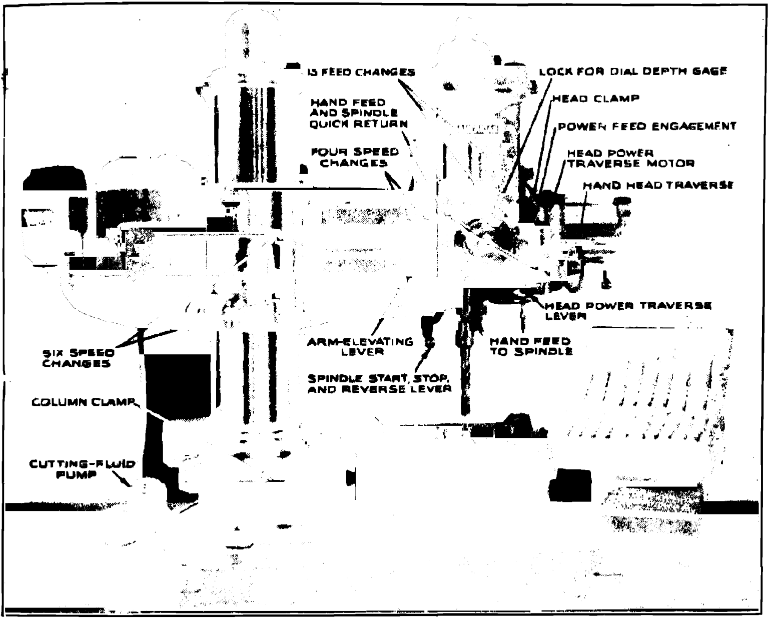


FIG. 14. The American Tool Works Co. Triple-Purpose, 17-in.-diam. Column Radial Drilling Machine.

A constant-speed motor drives by multiple V belt to the gear-change box. This unit is mounted on the rear end of the arm. A multiple-way box-type drill jig is shown mounted on the base. A complete set of drills, reamers, and taps is provided for machining the given part. Each tool is mounted in a shank to fit the quick-change chuck carried in the spindle. In this way the time of changing tools is kept very low.

Radial drills may be **classified** in several ways, such as:

1. Sensitive, light duty, high speed or heavy duty.
2. Fixed or portable.
3. Plain or universal.
4. Belt or motor drive.
5. With single, Fig. 14, right-angle, three-way, or four-way base.
6. With plain box, at right in Fig. 14, universal, swinging, or swiveling swinging table.

The diameter of the column and size of motor vary with the size and **duty** of the radial drill. Fixed bases, Fig. 14, are attached to the floor in a permanent position. **Portable** bases often are provided so that the drill may be clamped to floor plates adjacent to work to be machined. **Track-type** bases with either hand or power traverse also are available with means of clamping the base to the rails when the machine is to be used. The single base shown is most generally used, although a second at right angles also is common. These multiple bases permit one or more men to operate the drill press, so that while one man is machining the work on one base, helpers may set up another job on the second base. As a result, idle machine time is reduced to a minimum. Three- or four-way bases also are used for this purpose.

Various types of **tables** are provided for radial drills. Tables are convenient for mounting the work, particularly when it is small. They may serve also as a support for a work fixture in which the work is held in certain definite positions for drilling. The **plain box** table, at the right in Fig. 14, usually provides two large working surfaces, one horizontal and one vertical, both provided with T slots. This table may be clamped to the base of the machine by T bolts.

A **universal** table is used for angular work settings. It consists of a base on which is mounted a tilting worktable with two surfaces. Either face can be set in a vertical position or to any intermediate position. The table is clamped to any angle by two bolts, one on each side. Some universal tables also swivel about the base, having graduated dials provided for direct reading.

Radial drills of the **full universal** type may be obtained. The arms of the full universal machine may be rotated in a complete circle about its horizontal axis and about the vertical axis of the column. The head may be swiveled in a vertical plane on the arm. This feature is of special value in setting the spindle for angular drilling or tapping at any angle radiating from the center of a circle.

A **swinging-box** table is sometimes used as an auxiliary base. This base swings about the column at one end and is supported on the base by a foot at the other end. It can be swung out of the way when not needed. It has a top and a side face, each provided with parallel T slots. Some swinging-box tables may be **swiveled** by a worm and crank. Provision is made for clamping them at any desired angle, and a graduated scale on a stump is provided for convenient and accurate settings. **Round pedestal** tables are used in which the top face consists of a circular revolving worktable with radial T slots. These tables may be provided with a lubricant trough about the outer edge, and are convenient for average light service work.

On the large machines the end of the spindle is provided with a **Morse taper shank** to take the shanks of drills, boring bars, etc. One slot through the spindle is provided at the inner end of the taper, into which the tapered driftpin is inserted to drive out the shank held in place by friction. A second slot is placed nearer the end of the spindle, so that a locking pin may extend through the spindle and tool shank to support the tool. Often the tools are very heavy, and the head may be rapid traversed and the spindle lowered to engage the shank of a tool on a truck or table. The tool is carried to the working place and returned to its storage position after use.

Various types of **power drives** for radial drills are being used as follows:

1. A belt drive to tight and loose pulley, driving through a change-gear box.
2. Belt drive to constant-speed pulley, driving through a change-gear box. A driving clutch is between the single pulley and the gearbox.
3. Direct-connected, variable-speed motor drive with the motor mounted back of the column on an extension to the base or on the arm.
4. A constant-speed motor driving through a gearbox, both mounted back of the column on the arm, Fig. 14, or on an extension to the base, the motor replacing the constant-speed-drive pulley.
5. A constant-speed motor drive on the arm, with all change gears for speeds and feeds in the head.

The most popular modern drives are numbers 4 and 5.

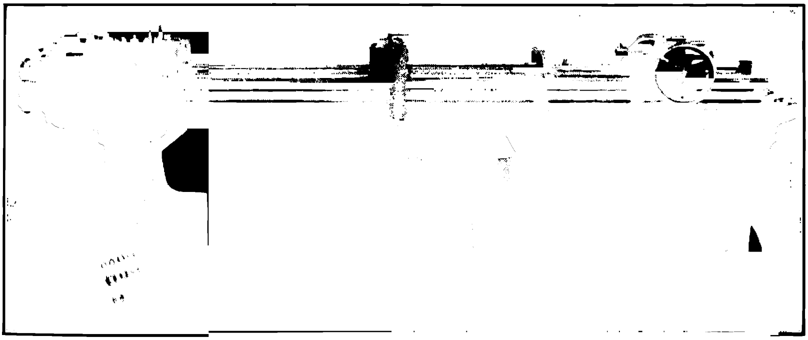


FIG. 15. The Pratt and Whitney No. 1 Two-Spindle Deep-Hole Driller.

This machine is built in two sizes: one with a 6-ft bed for drilling $14\frac{7}{16}$ in. deep, and the second with a $9\frac{1}{2}$-ft bed for drilling $33\frac{3}{8}$ in. deep. The machine consists of a long rigid bed, a fixed headstock at the left end which rotates the work, a combination drill guide and work-support carriage mounted in the center of the bed, and a drill carriage at the right end of the bed.

Drilling Machines — Deep Hole

A horizontal-type, two-spindle, deep-hole drilling machine, Fig. 15, may be adapted to a wide range of work, such as drilling rifle barrels, hollow spindles, bridge pins, boring bars, printing-press rolls, automobile crankshafts, camshafts, stay bolts, etc.

When the drilled hole can be relied upon to produce a clean true hole concentric in its length with the outside diameter, it may be reamed to exact size with a good finish. Higher speeds and feeds may be used when less accuracy and poorer finish are allowed.

The drill guide and work-support carriage has a hardened bushing which is machined to fit and support one end of the work and, at the same time, guide the drill tip and shank. A single-lip oil-tube drill

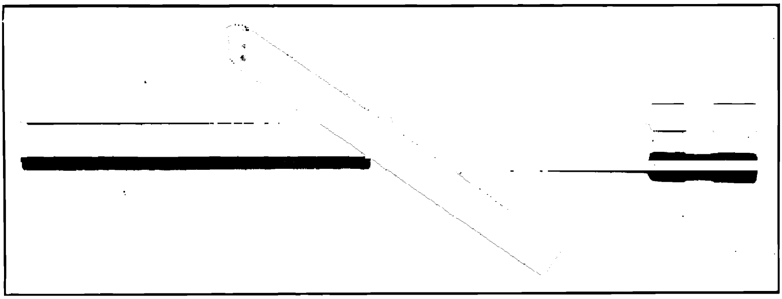


FIG. 16. Typical Single-Flute Oilhole Drills Used in the Pratt and Whitney Deep-Hole Drilling Machine.

The insert shows the high speed steel drill tip which is electrically welded to the long hollow shank.

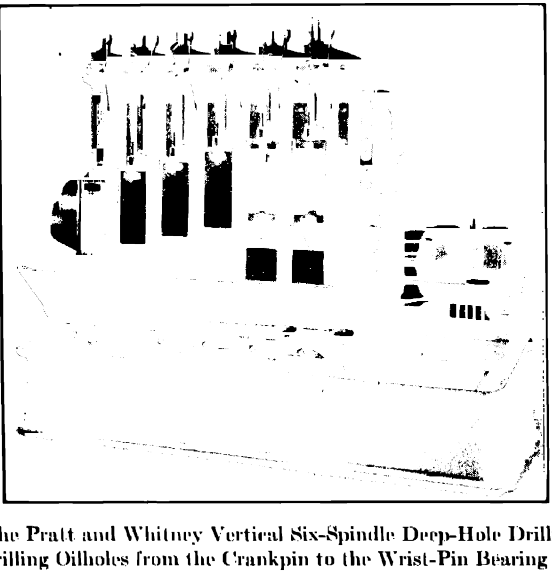


FIG. 17. The Pratt and Whitney Vertical Six-Spindle Deep-Hole Drilling Machine Setup for Drilling Oilholes from the Crankpin to the Wrist-Pin Bearing of a Forged-Steel Connecting Rod.

This front view shows the four left spindles inclosed carrying blanks being drilled in various stages. The sixth station from the left is ready to receive a blank. The fifth station has just been loaded. The connecting rod rests on dowel pins at the bottom and a center at the top. The work rotates and is fed slowly downward onto the stationary vertical drill. A $\frac{1}{4}$-in.-diam. hole 8 in. long is being drilled every $67\frac{1}{2}$ sec.

is used, Fig. 16, through which the cutting oil is forced at a pressure of several hundred pounds per square inch. This drives the chips back through the single flute. The oil and chips leaving the work are carried through the bushing into the interior of the work-support carriage, and thence to the pan under the bed, where the oil is screened. The machine provides three spindle speeds from 1,250 to 2,500 rpm. The feed-change gears, located in the headstock at the left end, feed the drill carriage on the right end of the machine with the drill to the left.

The six-spindle, vertical, deep-hole driller as adapted to the drilling of lubricating oilholes through connecting rods from the crank to the wrist-pin bearing is shown in Fig. 17. This machine consists of a heavy cast-iron bed on which is mounted a rigid column. This column carries the six work-spindle slides, together with their individual drive mechanisms. The six drills remain stationary and are mounted vertically on the bed beneath the spindles with the point upward. The spindles rotate the work in the fixture at the desired drilling speed. They are fed downward independently by power carrying the rotating work to the stationary drills.

This amounts to six independent machines under the control of one operator. Six high-pressure oil pumps, one for each drill, furnish the cutting oil under high pressure through the drill to its point.

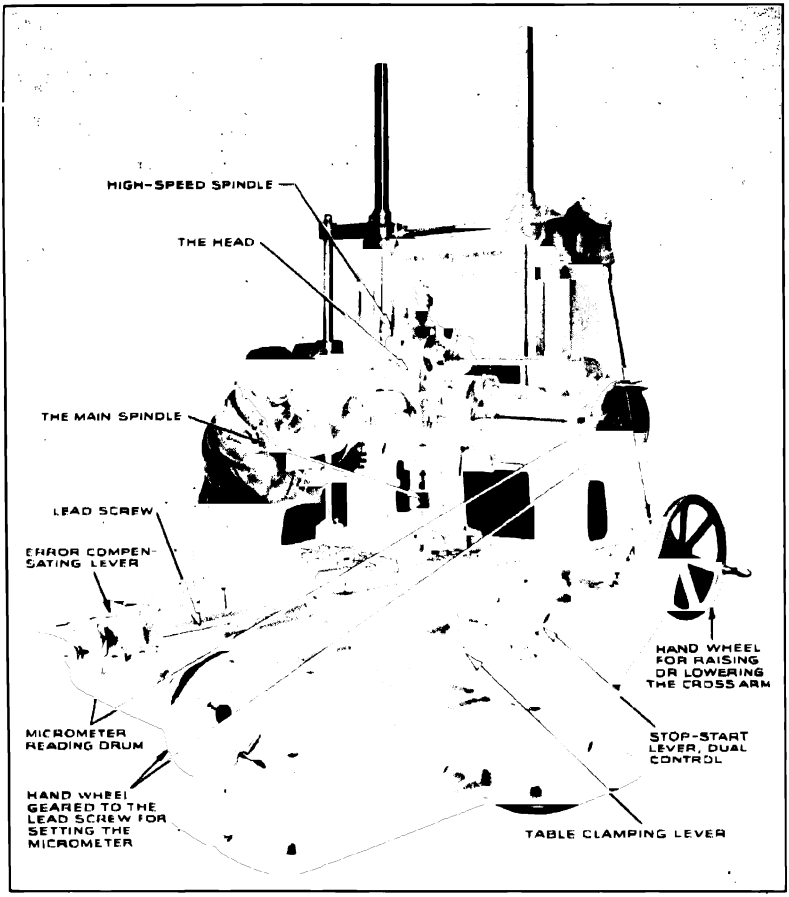
BORING MACHINES

Jig-boring machines: These machines are used to bore or finish holes in work such as drilling jigs, multiple drilling-head parts, and dies, which are very accurately spaced. They drill, bore, or ream as required.

The Swiss jig borer, Fig. 18, has two independent working spindles exactly 6 in. apart. The main spindle for larger work has nine working speeds arranged in geometrical progression from 45 to 400 rpm. The small or high-speed spindle has nine speeds ranging from 212 to 1,870 rpm. Three power feeds of 0.003, 0.005, and 0.008 ipr of each spindle are provided. The main spindle has a No. 4 Morse taper socket, and the high-speed spindle a No. 1.

For **locating** the work with respect to the spindles, two accurate lead screws arranged at right angles are provided. One traverses the table longitudinally on the bed, and the other traverses the head transversely on the rail. On the outer end of each lead screw is a large micrometer-reading drum which can be used for setting the table to 0.00005 in. accuracy. These drums are turned by large handwheels remotely placed so as to eliminate the influences of heat from the operator's body.

In order that the **accuracy** of the jig-boring machine may be even


HIGH-SPEED SPINDLE
THE HEAD
THE MAIN SPINDLE
LEAD SCREW
ERROR COMPENSATING LEVER
MICROMETER READING DRUM
HAND WHEEL GEARED TO THE LEAD SCREW FOR SETTING THE MICROMETER
HAND WHEEL FOR RAISING OR LOWERING THE CROSS ARM
STOP-START LEVER, DUAL CONTROL
TABLE CLAMPING LEVER

Courtesy Société Génevoise d'Instruments de Physique.

Fig. 18. The 1932 Model of the No. 5-B Sip Precision Jig-Boring Machine.

This table is movable longitudinally on the fixed bed, and the head is movable transversely on a rail. The motion of each is controlled by a very accurate lead screw terminating in a large micrometer reading drum at the front of the table and right end of the crossarm. This permits placing the work accurately under the spindle to within 0.00005 in. The operation shows a single-point boring tool mounted in an adjustable boring head for boring holes in a templet plate.

higher than that of its carefully made lead screws, each lead screw is fitted with an automatic correcting device. When the machine is completely assembled, the errors in the motion of the worktable and head are measured with extreme accuracy by comparison with a standard scale. The curve of the error as found is reproduced to a magnified scale on a strip of hardened steel. These strips, one for each lead screw, are fitted to the lower left edge of the worktable and the lower edge of the cross slide. A small lever follows the profile of the correcting strip and transmits to the Vernier of the reading drum the corresponding motion. This furnishes an immediate correction for every position of the worktable and cross slide. A dial-indicator device, in combination with a circular table, is used to set up the work edge to a position parallel to the lead screws. The work having been clamped firmly to the table, the point of the dial indicator is run along the edge of the work as the table is slightly rotated until the fluctuation of the dial gage becomes zero. This eliminates the necessity for loosening the work and shifting it about.

An inclined microscope may be attached to the end of the spindle for locating accurately the center of the spindle over the edge of the workpiece. The cross lines in the microscope coincide with the axis of the spindle. Accurate holes of standard size are successively bored by the end mills, which have nearly perfect concentricity and are within 0.00008 in. true size. The cutting is done entirely by the end of the mill because of the slight back taper. The holes are originated by drills which leave 0.01- or 0.02-in. stock for the end mill to remove. When the holes are not standard size, the adjustable boring head with a single-point boring tool is used.

There are three general methods of **locating hole centers** on these machines. One is to use an automatic center punch device. When the work is properly positioned under the center of the spindle, a center point of the punch device, raised by a cam action against a heavy spring, is released to mark the spot. A second method more frequently used, especially for steel pieces, is to mark the position of the hole by center drilling or by the use of a combination countersink and drill mounted, usually, in the high-speed spindle. The third method, used quite generally on cast iron, is merely to drill the hole without preliminary plotting, leaving 0.01- or 0.02-in. stock to be removed by the standard accurate end mill. The end mill rectifies the hole as to position, direction, and roundness. It is customary practice to drill all holes first and then bore them all without changing tools back and forth or checking locations between the successive holes. The accuracy with which settings can be repeated on the machine makes this practice feasible.

The **button method** is in common use by toolmakers for locating the position of holes. This involves fastening with a screw a small, hollow cylinder of hardened steel in a position on the work concentric to the hole to be made, as determined by micrometers or dial gages. The button, after being lined up accurately under the cutting tool, is removed and the hole machined.

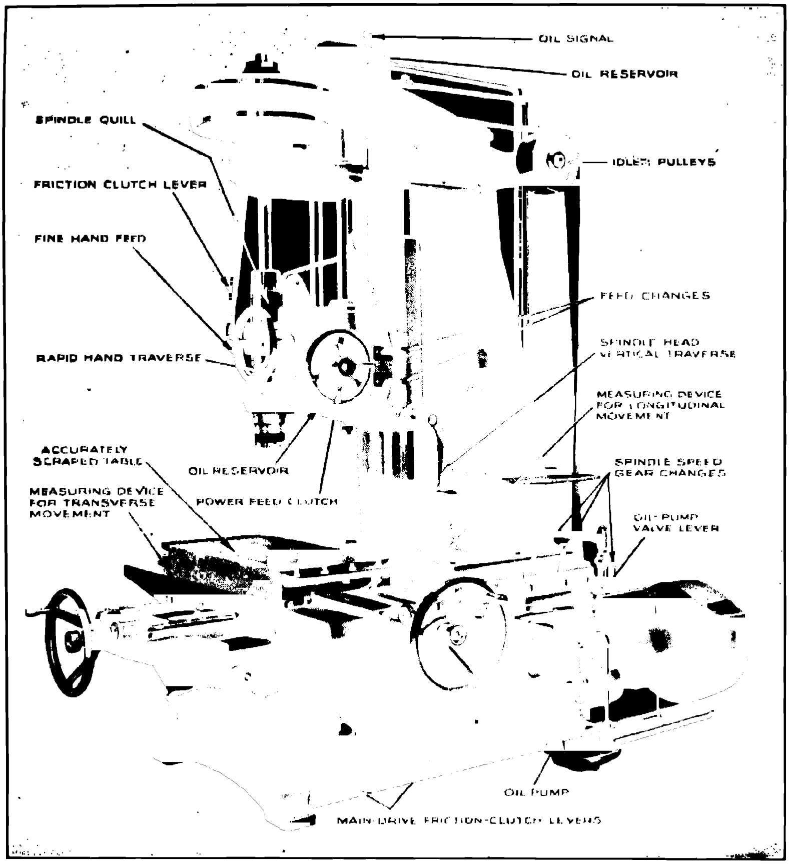


Fig. 19. The Pratt and Whitney Co. No. 2 Jig-Boring Machine for Work Requiring High Precision.

The table is movable longitudinally and transversely by lead screws operated by the large handwheels at the side and front. These lead screws are for roughly positioning the work under the tool. The final setting is made using the slow-motion handwheel for transverse and longitudinal setting in connection with the precision measuring rods and dial gage.

A jig borer with a fixed-bed, open-side construction which increases the range of its work capacity, makes its operation convenient, and provides a strong, rigid table and work support, is shown in Fig. 19. Power is transmitted to the spindle from a large variable-speed pulley at the rear and base of the column through a friction clutch controlled by the lever at the left side of the spindle.

Power is furnished to the machine through the single-pulley drive at the base. A speed gearbox provides a total of eight spindle speeds ranging from 37 to 492 rpm. A high-speed drilling and boring attachment provides an additional range of eight speeds from 137 to 1,820 rpm when attached to the spindle.

The feed gearbox, operated by a train of gears driving a vertical shaft from the spindle to the head, provides four feeds ranging from 0.0025 to 0.010 ipr of the spindle. The sliding **spindlehead** is clamped in any position on the column by binder bolts. The spindle quill in which the spindle is housed has a maximum vertical travel of 9 in. Graduations on the face of the quill permit boring to a definite depth.

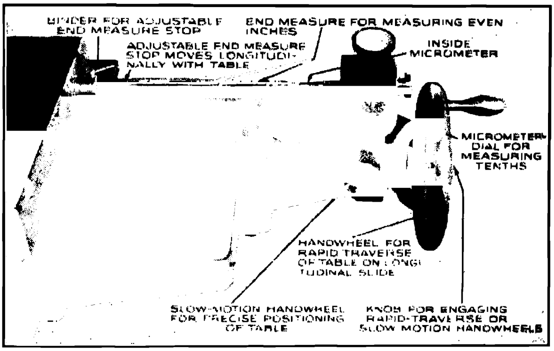

BINDER FOR ADJUSTABLE END MEASURE STOP
END MEASURE FOR MEASURING EVEN INCHES
ADJUSTABLE END MEASURE STOP MOVES LONGITUDINALLY WITH TABLE
INSIDE MICROMETER
MICROMETER DIAL FOR MEASURING TENTHS
HANDWHEEL FOR RAPID TRAVERSE OF TABLE ON LONGITUDINAL SLIDE
SLOW-MOTION HANDWHEEL FOR PRECISE POSITIONING OF TABLE
KNOB FOR ENGAGING RAPID-TRAVERSE OR SLOW MOTION HANDWHEELS

FIG. 20. A Close-Up View of the Precision Setting Tool Used in the Final Setting of the Table for Machining Operations on the Pratt and Whitney Jig Borer.

One of these setups is located on the right end of the table for the longitudinal adjustments of the table, while a second similar measuring device is located on the front of the machine for the transverse adjustments of the saddle. The table is moved quickly in both directions by large screws which have nothing to do with the accuracy of positioning the table. Accuracy to 0.0001 in. is controlled entirely by the end measurers, inside micrometers, and indicator dials. They keep a positive check on the position of the table at all times — before, during, and after boring.

The spindle nose is equipped with a No. 4 Morse taper and is shaped to take collets.

The **table** may be moved longitudinally or transversely, but during accurate machining is locked to the bed. The table is traversed rapidly in both directions by double-threaded screws operated by handwheels on the front and side of the machine. These screws are used only for moving the table which is accurately set transversely and longitudinally for machining by means of end measures, inside micrometers, and indicator dials shown in Fig. 20. Fine setting of the table is obtained by means of the small, slow-motion, knurled handwheels which operate the traversing screws through worms. Measuring rods and dial gages also are used on vertical milling machines for accurate hole boring. Drill presses or vertical mills provided with

universal tables, for longitudinal and transverse displacement, also are used extensively in less accurate jig-boring work.

Precision boring: Precision-boring machines for production work are made with vertical or horizontal spindles. Single-point tools of diamond or sintered carbide are generally used. They operate at very high speeds and fine feeds to produce accurate smooth holes in parts such as bronze bushings, aluminum alloy piston-pin holes, and connecting rod pin and crank bearing holes.

Fig. 21. The Ex-Cell-O Corp. Diamond Boring Machine Set Up for Rough and Finish Boring a 1-in.-diam. Piston-Pin Hole in Lynite Pistons.

One man, operating two machines, rough- and finish-bores 250 pistons per hr. The inspection of these pistons shows finished holes are within the following tolerances: 0.0001 in. for out of round, straightness, and diameter.

A horizontal type is shown in Fig. 21. The three parallel high-speed spindles are mounted in brackets carried on rigid bridges on the right end of the bed. The rotor of the boring tool driving motor is dynamically balanced and mounted directly on the spindle. It is rated at $\frac{3}{4}$ hp and rotates at 3,600 rpm. The table carrying the fixtures in the center of the machine is the only moving part. This table is operated by a specially constructed low-pressure hydraulic system whereby an extremely smooth and vibrationless action is obtained.

A 2-hp, inclosed, fan-cooled motor with double shaft extension drives, through flanged couplings, a special ball-bearing, geared oil pump at one end and a geared cutting-fluid pump at the other.

On the front of the table is a T slot in which the feeding-valve operating dogs are mounted. By means of these dogs, the operating cycle may be changed easily to suit any requirement.

A hydraulically operated fixture for rough and finish boring the piston-pin holes of three pistons at one handling is shown in Fig. 21. The fixture has three cylinders — one cylinder opens and closes the top, one cylinder operates the locating fingers for aligning the pistons, and one cylinder actuates the clamping mechanism. The operator loads three pistons into the fixture, and, by pressing the electric push button at the front of the fixture, the automatic six-way hydraulic valve, located at the back side, is moved through its operating cycle. The first action of this valve is to operate cylinder No. 1, closing the fixture cover, which contains also the clamping mechanism. The cover closes down on the piston, holding it tightly in place.

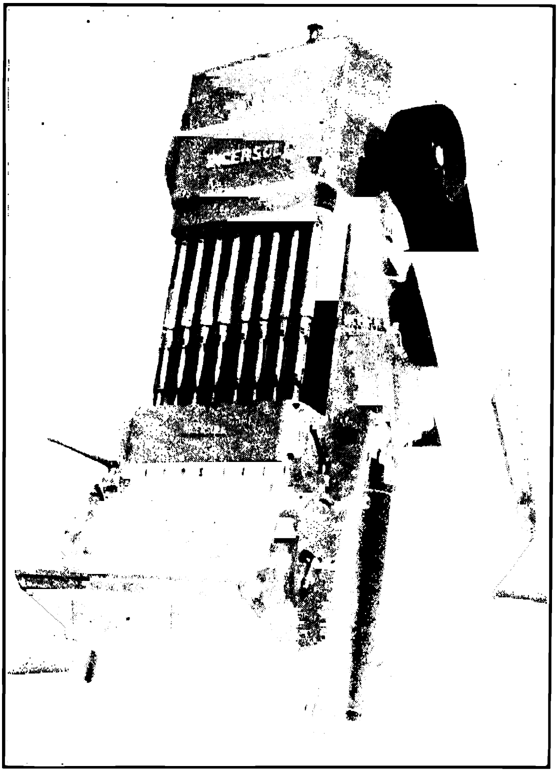


FIG. 22. An Ingersoll Milling Machine Co. Eight-Spindle Cylinder-Boring Machine for Rough and Finish Boring the Eight Cylinders of an Automobile Cylinder Block at One Setup.

The cylinder block is shown mounted in the fixture at the lower end of the boring bars. This fixture carrying the block is forced upward hydraulically against the boring tools. The operator loads the fixture and starts the machine, which causes the work to approach the cutters quickly, engage the cutting feed, and at the end of the stroke return to the starting point.

When this action is completed, cylinder No. 2 moves the locating fingers forward, aligning the rough piston-pin hole with the spindle. This forward motion of the locators also automatically locks the table and operates the valve so the machine cannot be started while locating. Cylinder No. 3 now comes into action and clamps the pistons from the inside of the skirt firmly in the locating bushings. Cylinder No. 2 then starts on its return stroke, withdrawing the locators and starting the table on its cycle. The fixture moves the work to the roughing spindles in fast traverse, changing to a slow cutting feed suitable for rough boring. After rough boring the front part of the piston-pin hole, the fixture moves across the gap to the rear hole at rapid traverse and then again changes to the slow cutting feed for rough boring. After boring the rear part of the hole, the table reverses, withdrawing the work from the tools at rapid traverse. This brings the pistons up to the finishing spindles, on the other end of the bed, which were started when the table reversed. After finishing the holes, the table reverses, and returns to the center where it stops and automatically closes a switch which again starts the automatic six-way valve to release the clamps, pushing the pistons about 2 in. above their seats to be removed and new pistons reloaded.

A heavy-duty vertically inclined eight-spindle cylinder **boring machine** for rough and finish boring at one pass of the work is shown in Fig. 22. This feeds the work upward to the boring bars by means of a hydraulic piston on each end of the boring jig. The boring bars are piloted both below and above the work. Hardened inserts are provided in the boring bars above the finishing cutters to prevent wear and to facilitate the replacement of worn parts. The cutters consist of inserted blades held in the bars. The roughing tools finish their operation before the finishing tools are engaged.

THREADING MACHINES

Thread-cutting machines: Internal and external threads may be cut on work with cutters held in hand tools, Fig. 23, hand power or portable tools, Fig. 24, or machine tools. The machine tools may be horizontal, Fig. 25, inclined, vertical, Fig. 28, and single spindle, or multiple spindle.

Threading machines may allow the helical teeth of the threading tool (tap or die) to establish their own lead after being started in the work, or the threading tool may be fed positively on the work at the required lead by a lead screw.

The work can be run over the tap onto the shank in through tapping, as shown in Fig. 28; or after the tool has threaded the work to the required distance, the work or tool must be reversed and backed off. There are several ways of reversing the tool or work. The lathe and some drill presses reverse the spindle to withdraw the threading tool. This may be done by having two driving clutches, one for forward speed and one for reverse. The one desired is engaged. Many standard drill presses have built-in reversing or tapping attachments which drive the tap forward when tapping, but reverse the spindle to withdraw the tap when it is lifted. Most radial drills have standard built-in reversing attachments, but in upright drills they usually are classed as an extra. A reversing motor often is used to change the direction of the threading tool at the end of the threading operation. Auxiliary tapping attachments, as shown in Fig. 37, may also be used in connection with standard drilling machines for threading where the tool has to be backed out of the work after completing the threading operation.

FIG. 23. The Toledo Three-Way Hand Threading Pipe and Conduit Die Holder Used in Cutting a Long Running Thread on a ¾-in.-diam. Conduit.

The Toledo malleable cast-iron pipe vise is attached to a portable workbench. The vise jaws accommodate themselves to any irregular shape and will clamp anything that will go inside the vise.

A hand **stock** or wrench to hold dies for threading pipe is shown in Fig. 23. This is a three-way stock, so that dies of three different sizes are available as required on any piping job. A small set of taps and dies, together with a hand wrench for driving the taps and a hand stock for holding the dies, is shown in Fig. 83.

A small **portable** electric tapping machine is shown in Fig. 24. This 9½-lb machine, made for various voltages, is designed for tapping holes up to ¼ in. diam. in steel, ⅜ in. diam. in cast iron, and ½ in. diam. in brass or aluminum. The tapping speed is approximately 300 rpm with a faster reversing speed. When the tap is pushed into the

FIG. 24. Black and Decker No. 2 Ball-Bearing Portable Electric Tapper Designed for Tapping Threads in Steel, Cast Iron, Brass, etc.

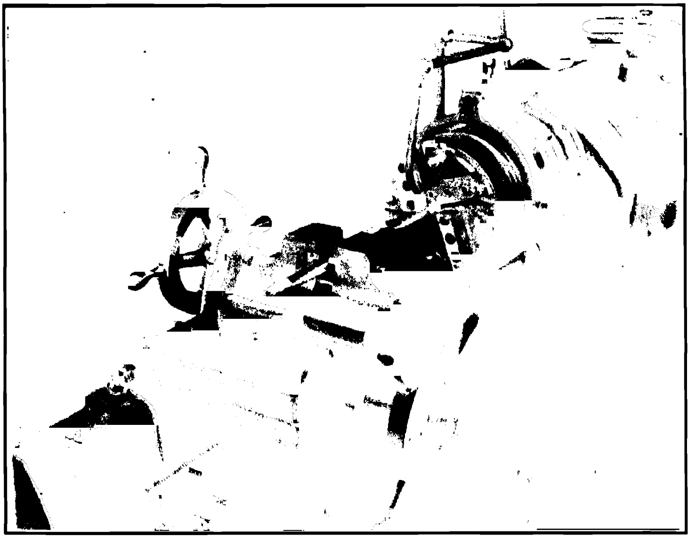


FIG. 25. The Murchey Machine and Tool Co. Single-Head Bolt and Pipe-Threading Machine, Using Tangential Chasers.

The smaller No. 11 machine will produce National coarse threads on bolts from ¼ in. to 1 in. diam. The self-contained 2-hp motor provides flexible speeds from 68 to 563 rpm. The work is clamped in the vise by the handwheel at the left. The carriage is hand-fed by the handwheel in front operating a pinion engaging the rack. Accurate power feed is obtained through the lead screw.

hole, the rotation is right hand, but is turned to left hand when the operator pulls backward on the machine to withdraw the tap.

The horizontal bolt and **pipe-threading machine**, Fig. 25, is made having one or more spindles. The die head, equipped with tangential chasers, is self-opening and -closing for any desired length of thread. A vertically and horizontally adjustable vise is provided so that the work of any shape may be centered with the die head. The vise is mounted on a carriage power fed by a lead screw to and from the head. Various power feeds of the work and speeds of the dies are provided. In other machines of this type the work is held stationary while the die rotates and is fed along the bed on the work. A reversing motor makes it possible to cut right- or left-handed threads. A cutting fluid of the sulphurized-oil type usually is forced to the die from a pipe or through the spindle.

FIG. 26. The Cutting-Off Head on the Toledo Pipe-Threading Machine.

This shows the four double-edge high speed steel cutters which cut simultaneously as they are fed in radially by means of the ratchet handle at the top. This is for cutting off 1-in. to 4-in. standard pipe.

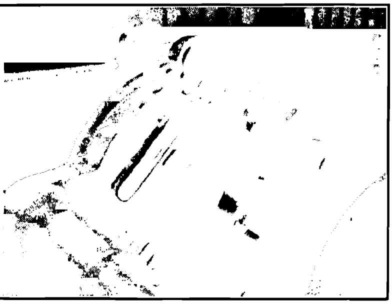


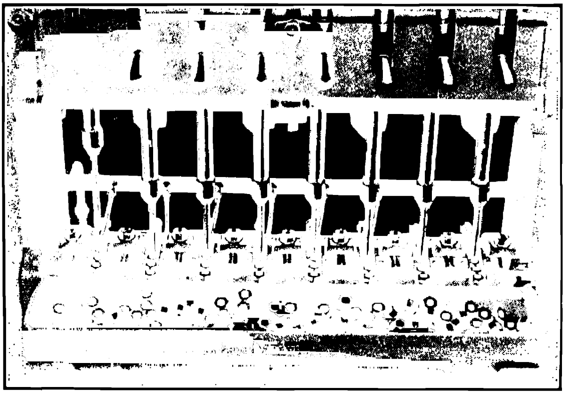
FIG. 27. The Toledo Pipe-Threading Die Attached in Front of the Cutting-Off Head.

The die is closed by the lever and toggle at the top and is in position for threading. At the end of the cut, the toggle lever is raised, thereby opening the head, i.e., radially withdrawing the six chasers, for backing off.

The heads of a cutting-off and **pipe-threading machine** are shown in Figs. 26 and 27. Six spindle speeds are available from a 3-hp motor. The high speeds are for cutting off and the low speeds for threading.

The machine has a capacity for threading a standard pipe from 1 to 4 in. diam. A separate set of dies, Fig. 27, is available for each size of pipe, thereby insuring proper rake and relief. Four chasers are provided in the die for the 1-in. and 1¼-in. pipe, and six chasers for larger sizes. All speeds are available in either forward or reverse direction. Standard threading times are as follows: 2-in. pipe threaded in 18 sec.; 3-in. in 30 sec; 4-in. in 42 sec. Cutting off times are as follows: 2-in. pipe cut off in 3½ sec; 3-in. in 7 sec; 4-in. in 9 sec. The cutters, Fig. 26, may be square ended or beveled so that the end of the pipe cut off is chamfered to facilitate subsequent threading. A 2-in. high-speed machine for threading pipe from ⅛ to 2 in. diam. provides cutting-off speeds of 134, 204, and 336 rpm, and threading speeds of 40, 60, and 100 rpm.

The National semiautomatic **nut tapper** in Fig. 28 will tap all sizes of square and hexagonal nuts from ½ to 1 in. diam. Larger machines have greater capacities. The taps are lowered gradually at a rate equal to the lead of the tap, thus eliminating sudden and violent tap strains. By introducing eight spindles in this design, or more on the larger machines, the machine will maintain a pace to keep one operator constantly busy. The spindles can be adjusted vertically to suit various lengths of taps, and the taps can be removed for unloading the nuts or inserted again in the sockets while the spindles are revolving.



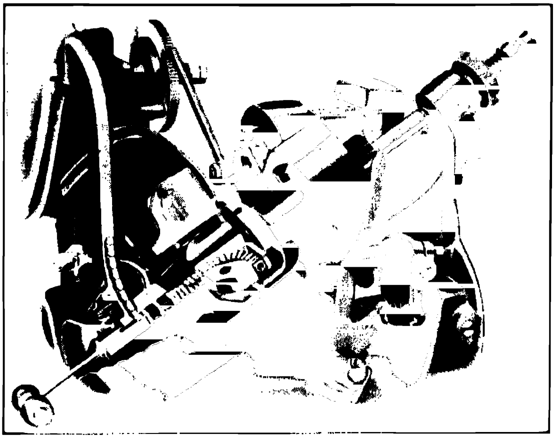
Courtesy National Machinery Co.

FIG. 28. The Feeding Table and Nut Pan of the National 1-in.-Capacity, Eight-Spindle Semiautomatic Nut Tapper.

Each spindle carrying a tapper tap is raised and lowered automatically by a 3-step cam. The cams are timed so the spindles rise and lower in consecutive order. Each step on the cam furnishes a different staying or raised time of the spindle to meet the needs of the operator for feeding. The operator merely slides the nuts from the pan into the nut guides and, when the spindle is raised, pushes the row of nuts forward under the tap. The nut blanks feed over the tap and are collected on the long shank. When the shank is full, the tap is removed from the chuck, the nuts taken off, and the tap rechucked.

The Holmes Engineering Co. semiautomatic **tapping machine** has four or six nearly vertical spindles operating together rather than successively as those of the National nut tapper. It is used to tap parts in quantities where tap reversal is required. There are two sets of fixtures carrying the work for each spindle. While the work in the fixture engaging the tap is being machined, that in the second fixture is being replaced. When the first lot has been machined, the second fixture is shifted into line with the spindle and machined.

The National Machinery Co. automatic tapper using a 90-deg-angle **bent tap** for continuously and automatically tapping blank nuts is shown in Fig. 29. The feed chute and nut holder are cut away, and the tap holder is open to show the operation. The tap spindle has a short lateral travel. After the injector has received a blank from the chute and fed it into the nut holder, the spindle advances and forces the tap into the nut during the completion of the tapping.



Courtesy National Machinery Co.

FIG. 29. Automatically Tapping Nuts Using a Bent Tap.

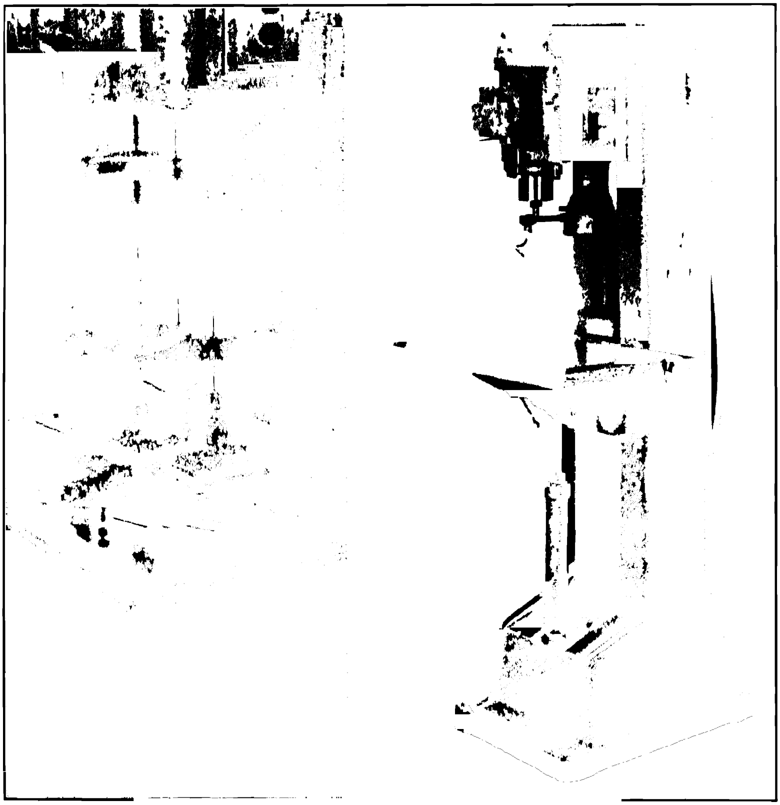
A close-up view of the head or tap holder open shows how the tap is supported and held central by tapped nuts. The hopper at the upper left is filled with hot-pressed or cold-punched and blanked nuts. They are fed automatically from the hopper down the feed chute to the injector which, by a reciprocating movement, feeds the blanks one at a time into the nut holder onto the rotating tap. The tapped nuts pass up the shank of the tap and are ejected off the end and fall from the machine.

These bent-tap nut tappers are built in a complete range of sizes in order to handle most economically all sizes of nuts from No. 1 to 1 in. incl. They are geared to run a tap at a speed of 3,000 rpm on No. 2 brass nuts, giving an output of 300 nuts per min, to a tap speed of 125 fpm on 1-in.-diam. steel nuts, resulting in an output of 7–12 per min, depending upon the number of threads per inch.

As a rule, carbon-steel bent taps are used by the majority of nut manufacturers. For closer fit nuts, ground high speed steel taps are frequently used.

The spindle in the **high-speed tapping machine,** Fig. 30, is fed by an air cylinder. Low-pressure air is used, and suitable controls allow adjustment of feed and pressure required. Sensitivity of adjustment synchronizes the feed with the lead of the tap, and tap breakage is practically eliminated. The cone clutch in the head drives the tap in the forward cutting direction on the down stroke and automatically reverses the rotation of the spindle, at a 2 to 1 ratio, on the up stroke.

These machines are designed to cover various ranges. The No. 1 tapping machine, illustrated, has a capacity of $\frac{3}{16}$ in. (or No. 10 tap) in steel, or $\frac{1}{4}$ in. in cast iron, aluminum, die cast metal, or brass.



Courtesy Snow Manufacturing Co.

FIG. 30. The No. 1 Air-Operated, Electrically Controlled, Automatic Tapping Machine

A vise holding the work may be quick acting and operated automatically, semiautomatically, or manually, so that parts fed either by hand or from dials, magazines, or hoppers can be threaded, tapped, or drilled at very high rates. The insert at the left shows a quick-acting vise mounted on the table of the drilling machine for cross drilling a handle hole in the head of a screw. The microswitch to the left of the drill does not allow the cutting operation to start until the work is properly clamped.

Holes can be tapped as fast as the parts can be presented to the tap. The following **example** illustrates the proper estimating of production possibilities on these machines.

The speed at which parts can be tapped is determined by two factors, such as the actual tapping time (cycle time) and handling time.

The actual tapping time may be determined as follows, being given the material of SAE 4140 steel, the tap size of ¼-28 and the tap depth of ½-in. full thread in a through hole.

The spindle speed must be an estimate based on the various characteristics involved — style of tap, type of cutting oil, type of material, percentage of thread, etc. For the SAE 4140 steel, 40 fpm or 611 rpm would apply to give 10 rev per sec.

The number of revolutions required for the ½-in. depth is 14 turns and for the reverse (2 to 1 ratio), 7 turns. An allowance for clearance, chamfer, etc., is 7 turns, to give a total of 28 turns. This would indicate that the total actual tapping time should be approximately 3 sec.

The handling time is determined by the size and shape of the part and the type of fixture to be used, hand feed, clamp, index, magazine feed, etc. In the event that an air clamp fixture is used, such as that illustrated at the left in Fig. 30, the handling time would be approximately 1½ sec. The total time for the job would, therefore, be 4½ sec. The result is a production estimate of 800 pieces per hr gross.

FIG. 31. The E. J. Manville Machine Co. No. 1-B Thread Roller.

Multiple adjustable-spindle tapping machines often are used for tapping small holes in a part such as a cylinder block or housing. Tapping and threading also are done frequently alone or in combination with other machining operations on bar stock in screw machines of the hand or automatic type, as described in Chaps. XI and XII.

Thread-rolling machines: The practice of **thread rolling** also is used extensively today in manufacturing screw threads. Bar stock of the nominal diameter of the bolt is first upset to form the head, after which the head is trimmed to shape. Just before trimming, but in the same machining setup, the shank is extruded or drawn out to reduce to the pitch diameter that portion on which the threads are to be rolled. The screw blanks with trimmed heads and extruded shanks are fed to the thread-rolling dies of the machine shown in Fig. 31. This thread-rolling process gives a thread of cold-worked material which is strong, smooth, and accurate as to size.

ATTACHMENTS AND ACCESSORIES FOR DRILLING, BORING, AND THREADING MACHINES

A wide range of accessories is required in the varied work pertaining to drilling, boring, reaming, and threading. The accessories most generally used come under the heading of **chucks** for holding the tools, **vises** for holding the work, **jigs** or **fixtures** used to hold the work, **multiple-drill heads** for increasing the number of spindles and tools, **speeding-up** attachments, and **tapping** attachments. Various types of the above are illustrated and described below.

Courtesy Jacobs Manufacturing Co.

FIG. 32. A Plain-Bearing Drill Chuck.

The body is provided with a threaded hole or a plain tapered hole in which is fitted the driving taper shank which, in turn, engages the spindle of the machine. The outer sleeve is forced onto the driving nut.

Chucks for Drilling, Boring, Reaming, and Threading Tools

A variety of types of chucks is used for holding the cutting tools in drilling, boring, reaming, and threading. Figure 32 shows a **plain**

self-centering drill chuck used for holding drills, taps, and reamers having cylindrical shanks. A key, having a T handle and a piloted small bevel gear the teeth of which engage the teeth of the sleeve, as indicated, is used for turning the sleeve and nut. The teeth in the nut, being slightly helical, force the three jaws conically inward or outward as the sleeve is turned. A hollow spindle shank may be used so that long cylindrical work can be held in the chuck.

For light work, **hand chucks** are made so that the sleeve may be turned by hand rather than by the use of the key. These chucks are provided with Morse taper shanks to fit the spindles of drill presses. They may have a Reed or Jarno taper shank to fit the spindle of a lathe for carrying work for light machining, or supported in the tail-stock spindle to carry a drill for machining the rotating work. A clamp or dog on the drill, bearing on the carriage, must be used to prevent rotation if large drills are used.

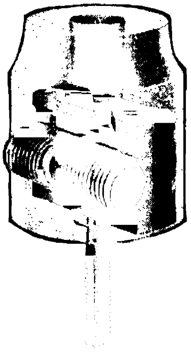


FIG. 33. The Skinner Positive-Drive Tapping Chuck.

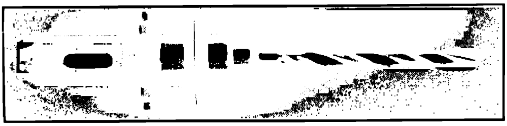
This chuck contains a set of adjustable positive-drive jaws for holding taps, drills, and other tools. The positive driving section of these jaws adjusts with the friction or centering jaws so that the centering and fastening of the tool are done in one operation. The two jaws are moved radially by the single screw having right-hand threads on one end and left-hand threads on the other. The screw is turned by a square-end wrench.

A **drill holder** supported on the tailstock center at one end and carrying a taper-shank drill or reamer in the socket of the other has an integral arm at right angles which rests on the carriage to prevent the rotation of the tool and its being drawn into the work.

Automatic chucks are so constructed that straight-shank drills from 0 to ⅜ in. diam. can be removed or inserted while the chuck is rotating. No key is required. The outer sleeve is gripped by the hand and elevated or lowered to release or grip the tool. Some chucks, called adjustable boring heads, Fig. 18, have one means of gripping the shank of a cutting tool and a second means of adjusting the eccentricity of the tool center with the chuck center. They are used in jobbing for boring with a single-point tool to any desired diameter.

Figure 33 illustrates a **positive-drive tapping chuck** for tools, such as taps, having square-end shanks. Interlocking opposed V jaws automatically center the tool shank while clamping it.

When a number of tools are required in the machining of a part in relatively small lots, the tools which are used may be fitted with collets interchangeable in a **quick-change chuck,** Fig. 14. Time is saved in changing tools during the machining operation.



Courtesy McCrosky Tool Corp.

FIG. 34. A Wizard Collet for Taper-Shank Tools with a Twist Drill in Place.

The tang of the Morse taper shank is seen through the collet slot. This collet holding a variety of types of tools fits interchangeably in the chuck as shown in Figs. 14 and 36.

The McCrosky Tool Corp. **Wizard chuck** for interchangeable collets is illustrated in Fig. 36. It consists of two main parts, a driving body with a Morse taper shank to fit the drill-press spindle, and a slotted collar to hold the collet carrying the tool in the driving body. A number of interchangeable collets are used in connection with the chuck. A regular Morse taper collet for taper-shank tools, such as a drill, is illustrated in Fig. 34.

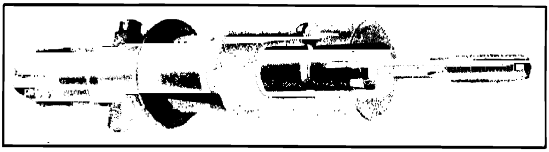


FIG. 35. A Phantom View of the Wizard Friction-Drive Tapping Collet.

This view shows how the hand tap is held in the bushing and the bushing in a taper plug which is drawn into a fiber-lined hole of the collet by the differential screw on the end. The tap is driven by its square end; the bushing is driven by two keys and floats in the taper plug. Should the spindle be raised too rapidly in backing out the tap, the bushing will be drawn out of the collet without injury to the thread.

Friction-drive tapping collets, Fig. 35, and adjustable collets for holding small straight-shank tools are available as well as friction-drive **stud-fitting collets** for driving studs into blind holes. These chucks and collets are available in several sizes.

Multiple-Spindle Drill Heads

For many years the cluster-type multiple-spindle drilling machine has been used for drilling simultaneously a number of holes in a given piece of work for moderate or high production. Unless special provisions were made, all spindles of the cluster head rotated at the same speed so that it was not good practice to have drills of large and small diameter in the same cluster. Each adjustable spindle consists of a telescoping drive shaft with universal joints at the upper and lower ends within the head. With the increased production of parts in quantities and with a variation in size of holes drilled in the piece,

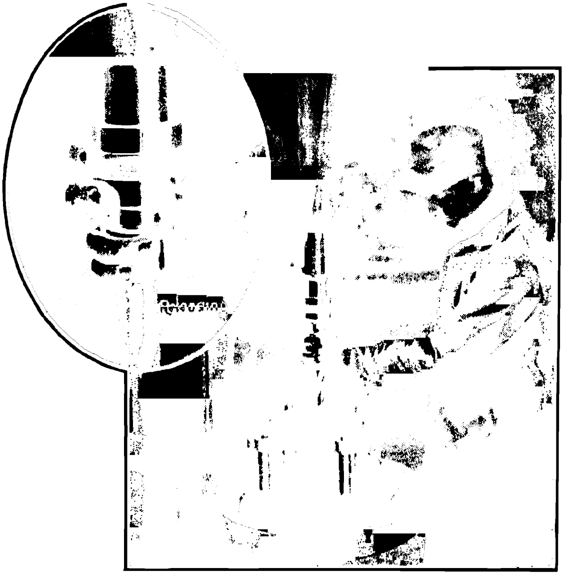


FIG. 36. A Drill-Press Spindle Fitted with a Wizard Chuck So That Drills of Different Sizes, or Drills, Reamers, and Taps Can Be Used Successively without Stopping the Spindle.

The collet, containing a twist drill, is being forced upward into the rotating chuck by the operator. The insert shows the position of the operator's hand when releasing the collet and tool from the chuck. Slight pressure of the thumb and forefinger on the knurled collar releases the collet instantly.

the adjustable multiple-spindle machine, Fig. 9, gradually gave way to the single-spindle drilling machine provided with a multiple-spindle drill head as shown in Fig. 8. These fixed-spindle drill heads are made so that each spindle has the proper speed for each cutting tool carried. All tools, however, have to be fed at the same rate.

A fixed-center-distance **multiple-spindle drill head** is shown at the left in Fig. 37. This indicates how the power is transmitted from the spindle of the drill press to the taper-shank driver of the multiple head and thence by spur gears to the various spindles. This unit is attached to the spindle quill of the drill press by means of the split holding sleeve, so that the head carrying a number of drills, reamers, or taps can be lowered to the work or raised from it after completing the machining operation.

Three types of spindles are shown. The standard **drill spindle** takes taper-shank drills or chucks mounted on taper shanks. The **tap**

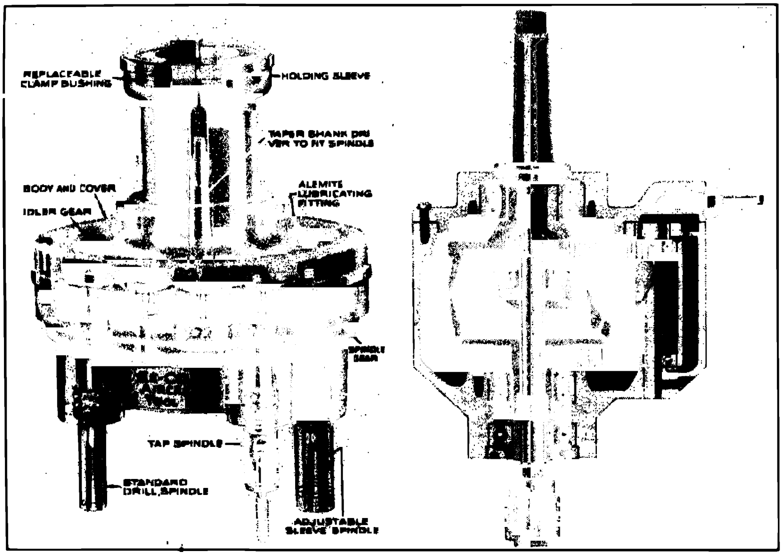

REPLACEABLE CLAMP BUSHING
HOLDING SLEEVE
TAPER SHANK DRIVER TO FIT SPINDLE
BODY AND COVER
IDLER GEAR
ALEMITE LUBRICATING FITTING
SPINDLE GEAR
TAP SPINDLE
STANDARD DRILL SPINDLE
ADJUSTABLE SLEEVE SPINDLE

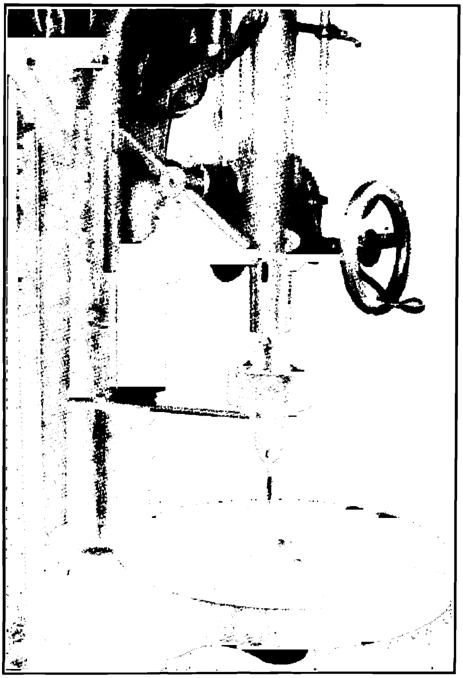
FIG. 37. Multiple-Spindle Drilling Head (*Left*) and Reversing-Spindle Tapping Head for Use on Single-Spindle Upright Drill Presses.

At the left is a phantom view showing a Krueger fixed-center-distance multiple-spindle head. Three available types of spindles, such as the plain, tap, and adjustable-sleeve spindle, are indicated. The drill head is clamped to the quill of the drill-press spindle by means of the clamp bushing. The taper-shank driver fits directly into the end of the machine spindle.

At the right is seen a sectional view of the Snow portable tapping head. The shank at the top engages the spindle for rotating drive, and the extended bar at the upper right bears against the column of the drill press to prevent the rotation of the head. When tapping, the chuck is driven by the cone engaging the upper driving plate. In withdrawing the tap the cone engages the lower plate and rotates in the reverse direction at a higher speed.

spindle is provided with a floating tap holder which allows the tap to cut freely. The shank of the tap fits into and is driven by a square-broached hole. When tapping is done, the spindles must be reversed to withdraw the tap either by reversing the motor or by the use of a reversing clutch. The **adjustable-sleeve spindle** has a fine adjustment which can be set quickly and locked to any desired depth of cut by means of a knurled nut (ASA B5.11, 1937). This is of special advantage when counter-boring, spot facing, or drilling blind holes.

Multiple-head spindles are also made in which a slight adjustment of the position of the spindle is possible. The **fixed-spindle** multiple head is made for a particular job and must be discarded if center distances are changed. The **adjustable-center-distance** head costs slightly more, but, where there is a possibility of small dimensional changes, it may result in an ultimate saving. When parts are produced in large quantities, special machines provided with multiple-drill heads, Fig. 13, are used. Many of the machine tools of this class are made up of well-standardized units consisting of sliding heads and feeding devices. The fixture carrying the work, the multiple head, and the bed are designed for the particular job. A single-spindle tapping head, with a friction clutch reversing device to withdraw the tap, is shown at the right in Fig. 37.



Courtesy Graham Manufacturing Co.

Fig. 38. A Speeding Attachment Shown Set Up in a 22-in. Upright Drill Press.

The speed of the drill is three times that of the driving shank. The attachment is used for speeding up small drills from 1/16 in. to 3/4 in. diam., and for speeds up to 3,000 rpm. The lever extending against the column of the drill press prevents rotation of the speeder body.

Speed-Up Attachments

It is frequently desirable to do considerable drilling with small-diameter drills in presses of comparatively large capacities. In order that appropriately high speeds can be obtained from the small-diameter drills, a so-called speed-up attachment or drill speeder is used. The attachments are usually provided with a Morse taper shank which engages the spindle of a press, Fig. 38. The spindle of the attachment in which the drill is mounted, either in a drill chuck or in an extended spindle to take taper-shank drills, is driven through offset gears at a speed higher than that of the spindle.

Threading Devices

When tapping or threading with nonopening dies is to be done on a drill press not equipped with a tapping or spindle-reversing attachment, a portable tapping device may be used, as shown at the right in Fig. 37. These attachments may be provided with a Morse taper shank to engage the spindle of the drill press, like that of the speed-up attachment, or made with a collar to be clamped to the spindle quill. The former must be prevented from rotating.

The bodies of these attachments contain a means whereby the upper spindle, engaging that of the drill press, drives the lower spindle in a forward direction on the downward or cutting stroke, but the lower spindle is reversed in its direction when the spindle is raised upward. The forward and reverse driving mediums may consist of ball clutches, friction-cone clutches, or friction disk of the single or multiple type.

Vises

Vises for holding the work are made in a wide variety of types and sizes. Often work to be drilled or machined on a drill press is placed on the table of the press and either held by hand or clamped by bolts. The Modern Machine Tool Co. round combination drill table and vise, made to replace the plain table of a drill press, is made in two parts. One part constitutes the movable jaw. It serves as the plain table, but in addition, many odd shapes can be clamped quickly for machining. The table swivels about the column of the press and about its own central axis, providing universal adjustment.

Sensitive drilling machines used for miscellaneous work should be provided with a small portable-type vise and different sizes of V blocks. The **vise**, similar in construction to that used on the planer, shaper, and milling machine, consists of a base and one movable jaw operated by a single horizontal screw. One vise of this type for drilling work has one edge machined to give a surface at right angles to the base and the face of the fixed jaw, so that the vise may be supported on its base or on the side for drilling at right angles.

Another vise of this type for job work or for small-quantity production, Fig. 39, is provided with an adjustable bushing plate to hold interchangeable bushings or drill guides of different diameters up to 1$\frac{1}{16}$ in. This bushing plate may be attached to the vise in any one of several places so that the bushing may be located properly to guide the drill or reamer to machine any desired part of the work. Improvised bushing plates for the production of small lots may be made of steel flats with guide holes drilled to suit the job. If production warrants it, the plates may be hardened to resist wear, or standard hardened bushings may be inserted. These bushing plates definitely locate the positions of the machined holes, making all parts produced interchangeable. Some **vises** for drill-press work are so constructed that work of irregular shape can be gripped through the automatic adjustment of flexible jaws or their supports.

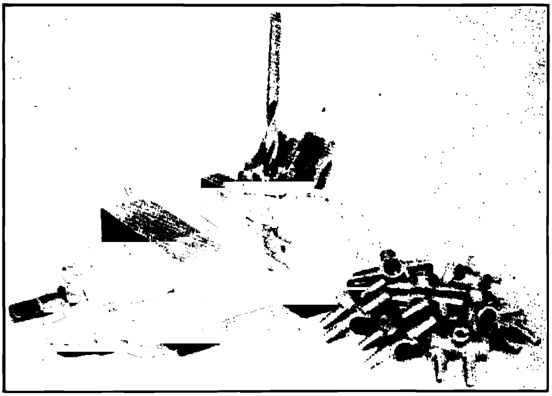


FIG. 39. The Graham Manufacturing Co. Drill Vise Provided with a Bushing Plate, Bushing, and Taper-Shank Drill.

A shell jaw to hold the gas-burner part to be drilled in small quantities is seated with Babbitt. Small quantities may be machined by these temporized jigs with little overhead cost.

The indexing chuck, Fig. 40, expedites the production of parts in small quantities, particularly when holes equally spaced on a circle are required.

The universal angle plate, Fig. 41, is another device used to advantage in supporting work in a definitely fixed position for machining. The work is usually held to the face of the vise by T bolts. The base is graduated to 360 deg horizontally while the table swivels 120 deg in a vertical plane. Verniers are applied to each graduating scale so that adjustment to within 5 min of any required angle is possible.

A **V block** forms a satisfactory support for drilling round work with small drills. The work may be held in a plain V block by hand while the drill is being fed or held in position by means of a clamping screw, as shown at the right in Fig. 42. It is usually difficult to start a drill on center when drilling round work, so that some kind of a guide bushing is desirable such as that held in the offset bushing plate at the left end of the V block. The bushing is adjustable for height as well as in its longitudinal position. Unless small drills are carefully guided, or

Courtesy Cincinnati Bickford Tool Co.

FIG. 40. Typical Production Work on a Single-Spindle Drill Press.

At the left a 24-in. round-column Cincinnati Bickford Super Service upright drill press is being used to drill four holes in a low-carbon steel part on 2¾-in. centers to a tolerance of ±0.0002 in. An accurately indexing Hartford chuck is used so that no further jigs are necessary. At the right a 1⅝-in.-diam. tapping operation is done in a forged steel shifting handle on a 28-in. round-column Cincinnati Bickford. A fixture is used to hold the work in position. A $1\frac{7}{16}$-in.-diam. hole is first drilled; the upper surface is faced, removing ⅛ in. metal; and the hole is chamfered by hand feed. The operation requires 4¾ min floor to floor. This shows the use of a jig and quick-change chuck for typical interchangeable shank tools for operations in sequence.

started in previously centered holes, excessive breakage occurs. This is particularly true when the holes intersect, as illustrated, for making driftpin slots, etc.

Jigs and Fixtures

Frequently the terms jigs and fixtures are used interchangeably. A device may be used as a jig at one time and a fixture at another. The commonly accepted definition of a **jig** is that it holds the work and guides the tool during the cutting operation. A **fixture**, on the other hand, consists principally of a clamping device for holding the work while it is being machined, with no regard to the guiding of the tool. The locating features should be such that the work always must be inserted in the same way so that the machined parts will be interchangeable. A jig may be justified to facilitate or speed up production or to promote accuracy and interchangeability of the product. The improvised V block shown in Fig. 42 facilitates drilling work in small quantities to produce interchangeable parts, or assists in machining one piece to any desired dimension. The V block, Fig. 42, would be a jig with the drill bushing, but a fixture without it. Jigs usually are associated with drilling, boring, and sometimes with reaming, whereas fixtures are more generally associated with broaching, grinding, milling, planing, shaping, turning, and tapping.

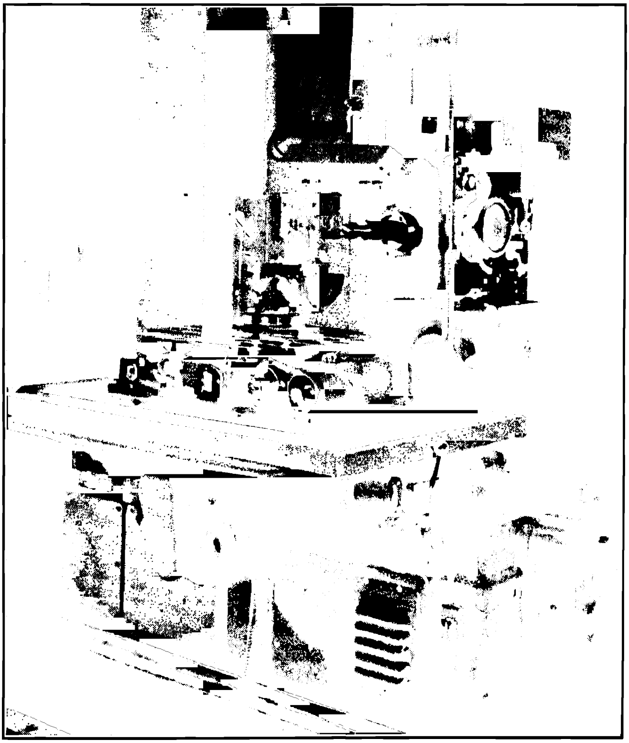


FIG. 41. The Boston Universal Angle Plate Mounted on a Power-Driven Rotary Table, in Turn Clamped to the Table of the DeVlieg 3A Jigmil.

The horizontally and vertically graduated scales make this tool extremely useful for job-shop work. The setup shows a part clamped to the face of a small angle iron to be drilled. Holes may be drilled and bored to accurate center distances on this machine.

In **drilling,** the drill point extends a distance from the end of the spindle or spindle housing of the drill press, so that it may be deflected considerably from its proposed path. For this reason a hardened and ground **guide bushing** (ASA Standard B5.6, 1941) is rigidly supported in a bushing plate over the work to guide the tool. The lower end of the drill bushing should be a distance from the surface of the work of approximately the diameter of the drill to allow chips to escape without clogging.

In originating holes in castings by drilling, such as in the hub of the wheel where the metal is heaviest, the surface may be irregular and cause the drill point to be forced to one side or the other of its center line before penetrating, or the material itself may have blowholes or soft spots or even hard spots on the interior which would cause the drill to be forced off center.

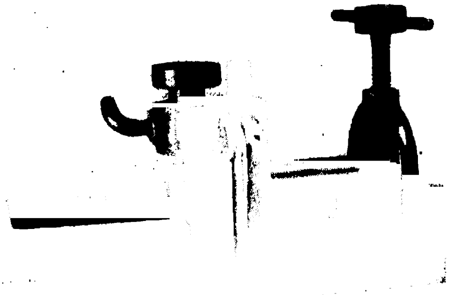


FIG. 42. A V Block Transformed into a Very Useful Holding Device for Round Work.

The right-hand yoke with a clamping screw may be used to hold the work in the V. The left-hand yoke with a hollow-head set screw also may be used as a clamp. Interchangeable slip bushings for guiding the drill may be clamped in the offset bushing plate. The graduated scale on the side permits fairly accurate location of the drilled holes.

In **boring,** it is good practice to provide a bushing, preferably of the ball-bearing type, in the bottom of the jig to pilot the boring bar at its free end. This prevents its deflection or wobbling. Counterboring is usually done with a rigid pilot, Fig. 60, or guide bushing. When no guide is provided, the rigidity of the tool and machine spindle is relied upon to prevent the tool from following other than its proposed course.

In **reaming,** guide bushings may or may not be used. They are used if there is a possibility that the drill or previously machined hole is sufficiently off center to make it desirable to have the reamer not only ream to size but locate the hole in the correct position. An end-cutting-type reamer, such as the rose reamer with cylindrical lands, is often guided by bushings.

In **tapping,** the hole to be tapped is first machined to the proper diameter and location, so that the tap simply follows the hole, no additional guide being desirable.

Classification of drill jigs: Several types of drill jigs are in use. The simple jigs, Fig. 8, for multiple operations, hold the work by clamping it against the top bushing plate in which guide bushings are located to guide the tools. The **bushing plate** is a vital part of the jig and many times is made an integral part, Fig. 8, or rigidly set up over the jig, Fig. 10; or it may be raised and lowered with the drill head, being attached to the clamping device only by means of at least two large guide pins, as at the right in Fig. 11.

A **box jig,** Fig. 14, permits the drilling of holes in the work from several sides, and for this reason is usually not attached to the table or bed. The interchangeable guide bushings for the drills and reamers are located in the several sides of the box.

A **trunnion-type jig,** Fig. 13, permits the drilling of holes by a spindle, in two or more faces of the part, by revolving the work and jig on fixed axes.

A **multiple-stage jig** or fixture is one in which operations on a piece are performed simultaneously or progressively, Fig. 8.

A rotating or **indexing jig,** having one or more fixtures at a station, is illustrated in Fig. 10. The work is machined progressively as it is indexed from the first to the last station. The table may rotate in horizontal or vertical planes.

DRILLS

Definition

A drill is an end-cutting tool to originate or enlarge a hole in solid material. When used on drilling machines, the drill usually is rotated and fed axially into the work while the work is held stationary. In lathe work, the work may rotate and the drill in the tailstock remains stationary; and in automatic turning machines, the work and drill both may rotate but in opposite directions to secure more efficient cutting speeds and chip removal.

Classification of Drills

Drills may be classified according to their construction or purpose, as follows:

1. Twist drill, Fig. 43, or helical fluted drill of the milled, forged, or flat type. This type is most generally used.
2. Farmer drill or straight fluted type used for drilling brass or sheet metal.
3. Flat drill with point ground on the end of flat bars.

4. Three- or four-fluted twist drill (core drill) for enlarging a cored, forged, or previously prepared hole, Fig. 49.

5. Center drill to drill and countersink the ends of shafts for mounting them on lathe or grinder centers, Fig. 50.

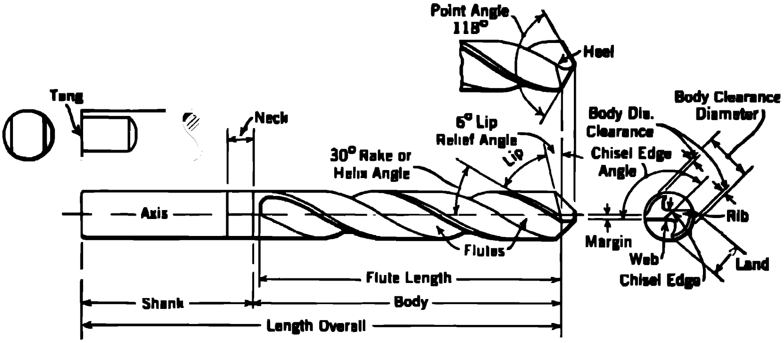


FIG. 43. A Straight-Shank Twist Drill with Nomenclature and Angles for General Use.

Values for specific purposes are given in Table 4.

The twist drill — nomenclature and angles: The twist drill having two flutes, Fig. 43, is the type most generally used in job-shop and production work, unless special conditions require the use of another. The principal parts of a twist drill are the **shank, body,** and **point.**

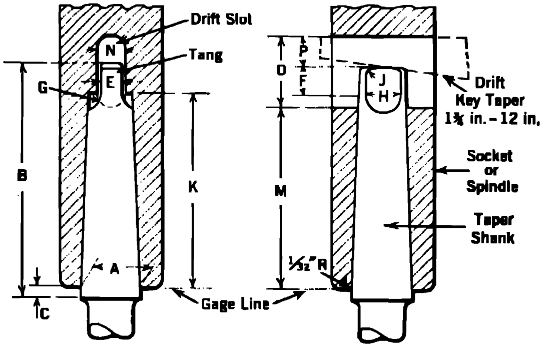


FIG. 44. A Sectional View of a Self-Holding Taper Shank Fitted into the Spindle of a Drilling Machine.

This shows how the tang fits into the slot through the spindle for positive drive, and how the taper shank is removed from the spindle by means of the drift.

The **shank** is that end of the drill by which it is held and driven. The most common types of shanks are the taper shank, Fig. 44, the straight shank, Fig. 43, the square taper for hand-bit stocks, and the square taper for ratchets. The **taper shank** supplies a means of centering and holding by friction the drill in the tapered spindle end of the machine. The drill is driven, however, by the flat **tang** on the small end of the shank, which extends part way into the slot through the spindle, as shown in Fig. 44. The Morse taper, Table 1, is used universally on drills, machine reamers, and boring bars. The **straight-shank** type of drill is held directly by the jaws of a drill chuck. For heavy work, a setscrew in an adapter bearing against a flat on the side of the shank will prevent drill slippage.

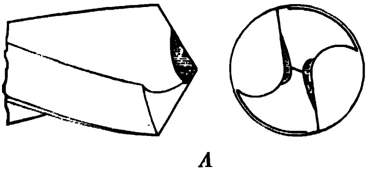
TABLE 1. SELF-HOLDING (SLOW) TAPER SERIES—BASIC DIMENSIONS (ASA B5.10, 1943)

No. of Taper	Taper per Foot	Diameter at Gage Line*	Means of Driving and Holding				Origin of Series
0.239	0.500	0.239	Tongue drive with shank held in by friction				Brown and Sharpe taper series
0.299	0.500	0.299					
0.375	0.500	0.375					
1	0.600	0.475					Morse taper series
2	0.600	0.700					
3	0.602	0.938		Tongue drive with shank held in by key			
4	0.623	1.231					
4½	0.623	1.500					
5	0.630	1.748					
200	0.750	2.000			Key drive with shank held in by key	Key drive with shank held in by draw-bolt	¾ in. per ft taper series
250	0.750	2.500					
300	0.750	3.000					
350	0.750	3.500					
400	0.750	4.000					
500	0.750	5.000					
600	0.750	6.000					
800	0.750	8.000					
1,000	0.750	10.000					
1,200	0.750	12.000					

* All dimensions given in inches.

The **body** or fluted portion of the drill is formed so as to give best sults in drilling, as determined by experience. The **flutes** are formed om the point nearly the whole length of the body in order to provide utting edges at the point, curl the chip within itself, provide a means escape for the chips, and allow a cutting fluid to reach the lips. The form of the flutes is such that the cutting edge is a straight line for the normal point angle of 118 deg. The angle of **helix** of the flutes, which provides the rake angle for the cutting edges, ranges in general drilling work from 18 to 45 deg, but averages about 32 deg.

The body is slightly tapered from the point to the shank to prevent rubbing while drilling. This **longitudinal** relief, which is of great importance in deep-hole drilling, varies from 0.00025 in. for small drills to 0.0015 in. for large drills per in. of length. In order to prevent the body from rubbing on the side of a drilled hole, a **body-diameter clearance** is provided. This leaves a small, cylindrical, finish-ground strip along the edge of the flute which is called the **margin,** the outside diameter of which is the full drill size. This margin helps to form the lip and, being helical along the body, bears against the side of the drilled hole and tends to pilot the drill point.



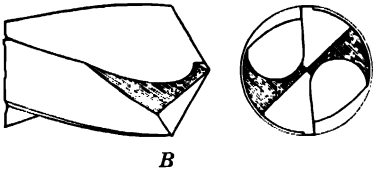


FIG. 45*A*. Side and End View of a Thick Webbed Drill Which Has Been Thinned.

FIG. 45*B*. A Thick Webbed Drill with "Crankshaft" Point Used in Deep-Hole Drilling.

The metal section which separates the flutes is known as the **web.** For average use, it is from 12 to 17 per cent of the drill diameter at the point, depending on the drill size. Some drills are made with constant thickness of web, whereas others are made with a normal thickness at the point which increases uniformly along the body to provide increased strength to the drill. When drills of the increased-web type become short through use, the web becomes disproportionately large and creates an excessive thrust in drilling. The point may be thinned, Fig. 45*A*, by grinding in the bottom of the flutes at the point.

The **point** consists of the entire cone-shaped surface at the cutting end of the drill. When drills are ground accurately on drill grinders, the smallest **relief angles** consistent with the feed and material being drilled are provided. For correctly ground drills, the relief angle should be from 6 to 12 deg, depending upon the feed.

The **feed helix** is the amount of helical relief back of the cutting edge to permit the drill to advance at its regular rate of feed. Lip relief as ground should equal the feed helix plus the relief. For a 1-in.-diam.-

drill having a feed of 0.013 ipr, the feed helix at the periphery is 13 min, but at the end of the chisel edge it is 1 deg 9 min. For soft materials, 15-deg relief is not excessive. This lip relief gives the cutting edge a chance to bite. If excessive, the cutting edges are too thin and chip off. If not enough and flank rubbing occurs, heat is generated, and the tool fails quickly. Drill grinding is one of the most important factors in drilling. The lip relief, the length of the lips, point angle, and the location of the dead center in relation to the axis of the drill must be carefully guarded by gages, Fig. 46. Machine-ground drills are greatly superior to those ground by hand, as more accurate and uniform results are obtained.

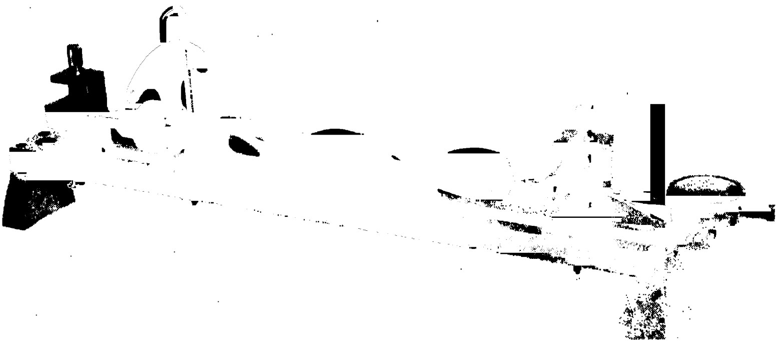


FIG. 46. A Measuring Device to Check the Lead of the Cutting Edges of a Twist Drill.

The advance of one lip over the other at any distance from the drill center is indicated on the dial gage. The relief angle back of the lip can be determined at any distance from the drill center by measuring longitudinal relief on the dial gage for various degrees of rotation as read from the graduated scale on the shank. Several sizes of V blocks are provided. The shank-supporting center is adjustable vertically by micrometer screw. The dial indicator pointer is first located on center and then raised a fixed distance for taking readings. In this way, readings may be duplicated or compared.

The **lip relief** should be greatest at the center, as all parts of the drill advance the same amount for each revolution, but the helix angle traveled by a point near the dead center is much greater than that at the outer edge, Fig. 47. The usual **point angle** or that angle included between the two cutting edges is 118 deg. In grinding a drill, the cutting edges should be at equal angles from the axes and of equal length so that each takes its portion of the feed. The helix angle of drills may vary from zero for the straight-fluted two-lipped drills for brass, bronze, very hard steel, and slate up to 45 deg for aluminum and marble. For average work 32 deg is standard. Where sufficient quantity of material is to be drilled, maximum efficiency is obtained by grinding the drill-point angle on a drill of proper helix to suit the special requirements of that material, as summarized in Table 4. Sometimes beveling or rounding off the outer corners of the lip of the drill increases tool life. This is of particular importance in drilling plastics and magnesium and when drilling thin sheets.

The **thick-web deep-hole** two-fluted drill for crankshaft oilhole drilling, Fig. 45*B*, is designed to give great strength to a long drill of relatively small diameter. The web thickness is about 40 per cent of the drill diameter. A 45-deg helix angle is recommended for cutting hard, brittle metals, and a 35-deg helix angle for cutting tough, ductile metals.

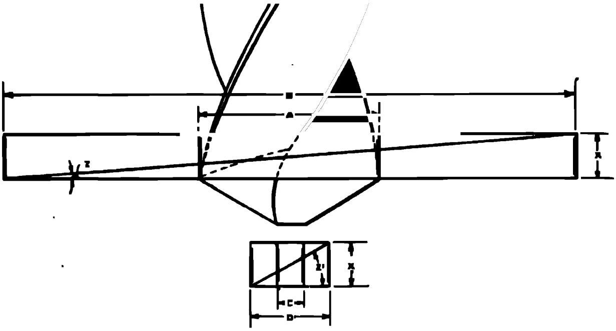


FIG. 47. A Diagram to Show That, for a Given Feed X of the Drill per Revolution, the Feed-Helix Angle Back of the Cutting Edge Equals Z at the Periphery and Z' at the Chisel Edge.

The drill should be ground with a relief greater than angles Z and Z' to provide true relief:

A = diameter of cylinder at drill periphery.
C = diameter of cylinder at chisel edge.
B = circumference of cylinder A.
D = circumference of cylinder C.
X = feed per revolution.
$\tan Z = X/B$.
$\tan Z' = X/D$.

For some purposes, **oilholes** are provided running from the shank through the ribs, so the cutting fluid may be delivered to the bottom of the hole being drilled just back of the cutting edge. This oil washes the chips back through the flutes, preventing clogging. It also provides a cooling medium for the drill point in the bottom of deep holes. These holes are formed by actual drilling before the twisting of the body to form helical flutes, or small tubes may be brazed in the periphery of the drill just back of the margin.

Single-flute deep-hole drills are used for drilling deep straight holes. One of high speed steel is shown in Fig. 16, while a carbide-tipped drill with nomenclature and generally used dimensions is shown in Fig. 48. Cutting speeds in steel of 130–350 fpm are recommended, with 250–300 fpm a good average. The high speed steel drills operate at about 130 fpm. The feeds range from 0.0003 to 0.001 ipr, with the lower values for the smaller drills and for less runout of the hole. The cutting oil must flow to the point through the drill shank with sufficient pressure and volume to force the chips away through the flutes.

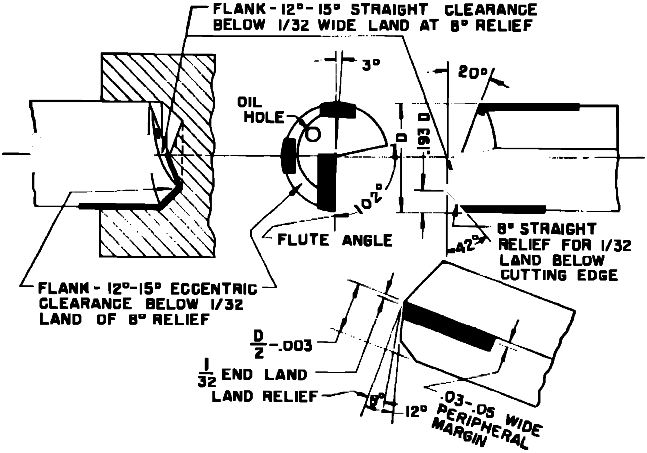

FLANK - 12°- 15° STRAIGHT CLEARANCE BELOW 1/32 WIDE LAND AT 8° RELIEF
3°
20°
OIL HOLE
D
.193 D
102°
FLUTE ANGLE
8° STRAIGHT RELIEF FOR 1/32 LAND BELOW CUTTING EDGE
42°
FLANK - 12°-15° ECCENTRIC CLEARANCE BELOW 1/32 LAND OF 8° RELIEF
D/2 -.003
1/32 END LAND
LAND RELIEF
8°
12°
.03-.05 WIDE PERIPHERAL MARGIN

FIG. 48. Nomenclature of a Single-Lip Deep-Hole Drill Tipped with Sintered Carbide Brazed to a Single-Flute Oilhole Shank.

The angles and sizes shown are generally recommended for drilling deep, straight holes such as gun bores. These drills are used on machines illustrated in Fig. 15.

Twist-drill sizes: Twist drills are made in many sizes and lengths, ranging in diameter from a few thousandths of an inch to 6 in. They are designated as follows:

Numbered drills from No. 80 (0.0135 in. diam.) to No. 1 (0.2280 in. diam.).

Lettered drills from A (0.234 in. diam.) to Z (0.413 in. diam.).

Millimeter drills from 3 mm (0.1188 in. diam.), by ½ mm, to 77 mm (2.9921 in. diam.).

The numbered and lettered drills are of the straight-shank or wire type. The diameter of shank and lands of both are ground to the same size except for slight back taper. The millimeter and fractional drills are made with both straight and taper shanks, but with taper shank only for larger sizes.

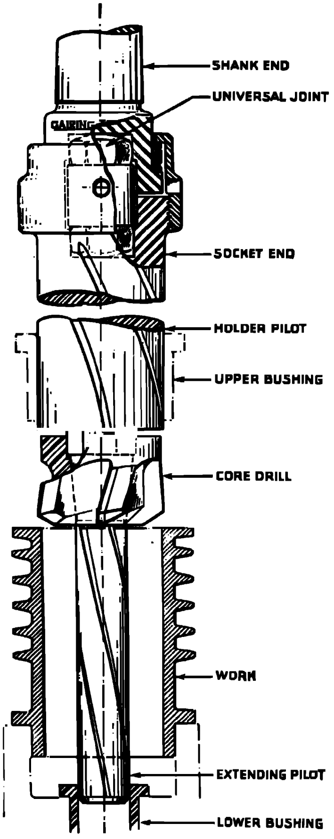


FIG. 49. A Gairing Full-Floating Double-Universal Toolholder and Renewable Core Drill for Core Drilling a Cast-Iron Cylinder.

The socket end of the tool is piloted in the bushing above the work; the pilot extending from the cutter is piloted in the bushing below the work. The shank end of the holder is driven from the drill-press spindle. The full floating between the shank end and socket end of the holder permits the cutting tool to be guided entirely by the upper and lower bushings, thereby eliminating any error in spindle alignment or eccentricity.

A revised series of sizes (ASA B5.12, 1949) combines these straight-shank drills according to size from No. 80 to $\frac{1}{2}$ in. diam. (137 drills), all in a short length and some in a long length, with corresponding flute lengths. The long drills are for production work where drill jig bushings (ASA B5.6, 1941) are used, Table 2. Straight-shank twist drills of fractional size and long length are given from $\frac{33}{64}$ in. diam. to 2 in., by $\frac{1}{64}$-in. increments to $1\frac{1}{4}$ in., by $\frac{1}{32}$ in. to $1\frac{1}{2}$ in., and by $\frac{1}{16}$ in. to 2 in. Taper-shank drills are given from $\frac{1}{8}$ in. diam. by $\frac{1}{64}$ in. to $1\frac{3}{4}$ in., by $\frac{1}{32}$ in. to $2\frac{1}{4}$ in., by $\frac{1}{16}$ in. to $3\frac{1}{2}$ in. diam. Larger drills are made by various drill manufacturers, Table 3. A new series of automotive straight-shank drills with definite lengths are set up, ranging from 0.2500 in. diam. to 0.6875 ($\frac{11}{16}$) in.

Tolerances have been set on the various features of all drills so that the products of different manufacturers will be interchangeable in the user's plants.

Miscellaneous drills: Where an existing opening is to be enlarged by the removal of considerable material, a so-called **core drill** is used. These core drills resemble the two-fluted twist drill, inasmuch as they usually have tapered shank and helical flutes. They have three or four flutes instead of two, as illustrated in Fig. 49. These tools are not suitable for originating holes in solid metal. Where considerable core drilling of a given large size is to be done, the replaceable shell drill, Fig. 49, may be used. This drill is especially adapted for enlarging punched or drilled holes and for rough boring cored holes in cast iron, malleable cast iron, steel forgings, etc., when large quantities are involved. One

TABLE 2. DIAMETERS OF NUMBER AND LETTER SIZE DRILLS AND REVOLUTIONS PER MINUTE (RPM) FOR A PERIPHERAL CUTTING SPEED OF 100 FPM

Number

No. Size	Diameter Decimal Equivalents	rpm	No. Size	Diameter Decimal Equivalents	rpm	No. Size	Diameter Decimal Equivalents	rpm
1	0.2280	1,675	28	0.1405	2,719	55	0.0520	7,346
2	0.2210	1,728	29	0.1360	2,809	56	0.0465	8,215
3	0.2130	1,793	30	0.1285	2,973	57	0.0430	8,903
4	0.2090	1,828	31	0.1200	3,183	58	0.0420	9,095
5	0.2055	1,859	32	0.1160	3,293	59	0.0410	9,316
6	0.2040	1,872	33	0.1130	3,380	60	0.0400	9,549
7	0.2010	1,900	34	0.1110	3,442	61	0.0390	9,794
8	0.1990	1,919	35	0.1100	3,472	62	0.0380	10,050
9	0.1960	1,949	36	0.1065	3,587	63	0.0370	10,320
10	0.1935	1,974	37	0.1040	3,673	64	0.0360	10,610
11	0.1910	2,000	38	0.1015	3,763	65	0.0350	10,910
12	0.1890	2,021	39	0.0995	3,839	66	0.0330	11,580
13	0.1850	2,065	40	0.0980	3,898	67	0.0320	11,940
14	0.1820	2,099	41	0.0960	3,979	68	0.0310	12,320
15	0.1800	2,127	42	0.0935	4,085	69	0.0292	13,060
16	0.1770	2,158	43	0.0890	4,292	70	0.0280	13,640
17	0.1730	2,208	44	0.0860	4,442	71	0.0260	14,730
18	0.1695	2,260	45	0.0820	4,658	72	0.0250	15,280
19	0.1660	2,301	46	0.0810	4,716	73	0.0240	15,920
20	0.1610	2,372	47	0.0785	4,866	74	0.0225	17,020
21	0.1590	2,402	48	0.0760	5,026	75	0.0210	18,190
22	0.1570	2,433	49	0.0730	5,233	76	0.0200	19,100
23	0.1540	2,480	50	0.0700	5,457	77	0.0180	21,220
24	0.1520	2,513	51	0.0670	5,701	78	0.0160	23,870
25	0.1495	2,555	52	0.0635	6,015	79	0.0145	26,340
26	0.1470	2,598	53	0.0595	6,414	80	0.0135	28,300
27	0.1440	2,653	54	0.0550	6,945			

Letter

A	0.234	1,636	J	0.277	1,379	S	0.348	1,098
B	0.238	1,605	K	0.281	1,359	T	0.358	1,066
C	0.242	1,578	L	0.290	1,317	U	0.368	1,038
D	0.246	1,556	M	0.295	1,295	V	0.377	1,013
E	0.250	1,528	N	0.302	1,265	W	0.386	989
F	0.257	1,486	O	0.316	1,209	X	0.397	962
G	0.261	1,463	P	0.323	1,183	Y	0.404	945
H	0.266	1,436	Q	0.332	1,150	Z	0.413	925
I	0.272	1,404	R	0.339	1,127			

holder will outlast a large number of cutters. Core drills are frequently tipped with sintered carbides for production work on cast iron.

In quantity-production work on large holes, it is often economical to combine tools such as drill and reamer. **A combination drill and tap** is shown in Fig. 80. A combination **drill and countersink,** illustrated in Fig. 50, is made in various combinations of body and drill sizes. They are used to countersink the end of work to be supported on machine centers.

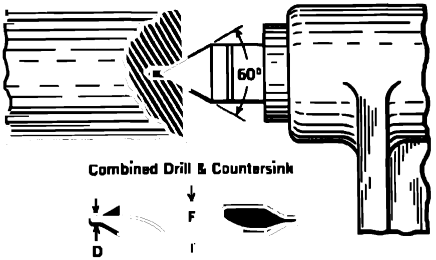


FIG. 50. Combined Drill and Countersink with Work Properly Mounted on a Center.

They are made in thirteen sizes from A-1 with 1/8-in.-diam. body and 3/64-in. drill, to N-2 with 3/4-in. body and 5/16-in. drill. Size E-2, commonly used, has 0.300-in. body and 1/8-in. drill and is 2 1/8 in. long.

MATERIALS FOR DRILLS

Drills made of **carbon tool steel,** listed as 1 in Table V-1, fill a definite need and find widespread application. Carbon-tool-steel drills should not be operated at high cutting speeds, although they are used for drilling practically all the common materials. The low initial cost of these drills makes them popular where their use is intermittent. They are not recommended for production work unless used on some of the free-machining metals.

About the same number of drills are being made of high speed steel as of carbon steel. **High speed steel** of the 18–4–1 type is recommended for production work in drilling practically all kinds of materials when high production and long life are required.

There are few materials, such as chilled iron, 13 per cent manganese steel, magnet steels, and steels over 400 Brinell, which are not drilled successfully with the regular high speed steel. For these purposes, **cobalt-high speed** steel, or drills tipped with **sintered carbide,** are recommended. The latter have but slight helix and also are used extensively for drilling abrasive materials as brick, marble, glass, rubber, slate, and tile.

High speed steel drills, **chromium plated,** and black **oxide-coated** drills are used with success as they provide low friction of chips in the flutes. Drills made of high speed steel, **nitrided,** offer possibilities for light work because of the high hardness of the surface.

Manufacture of Drills

Small drills usually are made from the solid bar stock with the body and shank integral. Even the larger sizes of carbon-steel drills are made in this manner. When high speed steel or cobalt-high speed steel is used, the body is made of the tool steel, and the shank, either straight or tapered, is made of a high-carbon or alloy steel. The two are butt welded together, after which the flutes are forged straight, the body twisted to the proper helix, the whole drill machined, heat treated, sandblasted, and finish ground for service. The high speed steel stock may be purchased in bars with the flutes already rolled.

Many drills, particularly the small ones, are machined from solid round rods by milling the flutes with form milling cutters on automatic millers.

Sleeve, Socket, and Drift Key

The end of the spindle of a drill press, boring mill, etc., is provided with a self-holding taper hole of a size in proportion to the size of the machine. Cutting tools, such as drills and reamers, chucks, multiple heads, drill speeders, tapping attachments, etc., are often provided with taper shanks to fit the taper in the spindle, Fig. 44. When the number of the taper of the tool is less than that of the spindle, it is fitted to the larger spindle taper by means of **sockets** or **sleeves,** Figs. 51 and 52. The **drift key,** Fig. 44, is in position to be driven to the left to disengage the shank from the socket.

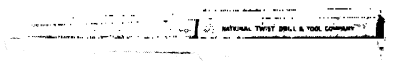


FIG. 51. Steel Sockets with Finished Shanks for Taper-Shank Drills.

The shank has one Morse taper, while the hole has a taper size one number or more smaller.

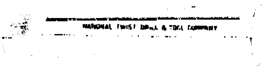


FIG. 52. Sleeves for Taper-Shank Drills.

These sleeves have one Morse taper on the outside and another of smaller size on the inside. The small taper shank of small drills is inserted in the internal taper of the sleeve, and the sleeve in turn fitted into the taper of the spindle. One or several may be used in any setup.

SPEEDS AND FEEDS FOR DRILLS

The **feed** of the drill is usually expressed as the amount of advance in inches per revolution of the drill. The feed may be expressed in inches per minute. This is the product of the feed per revolution and the revolutions per minute. The feed should be small for small drills and large for large drills, as indicated in Table 3. Heavier feeds may be used in cutting soft metals, such as cast iron, brass, aluminum, etc., and lighter feeds may be advisable when cutting very hard cast iron or steel, or steels which work-harden appreciably.

The drill may be fed or forced into the work by hand or power feed.

Often when using small drills, hand feeding is preferable as the resistance to penetration can be detected and drill breakage avoided. In drilling with no guide bushing, the drill should be started slowly by hand until it centers itself, after which the power feed may be engaged.

The **speed** of a drill may be represented by the peripheral speed of the circumference expressed in feet per minute or reduced to revolutions per minute for drills of a specific diameter. The peripheral speed in feet per minute is the product of the circumference of the drill in feet and revolutions per minute. Recommended speeds for standard fractional drill sizes and speeds for drilling several common metals are given in Table 3. These speeds should be reduced to 40–50 per cent for carbon-steel drills. The National Twist Drill and Tool Co. recommends a speed reduction of 10 per cent (feeds 10 per cent) for holes having a depth three times the drill diameter *d*, 20 per cent for 4*d*, 30 per cent (feeds 20 per cent) for 5*d*, and 40 per cent for 6–8*d*. The **crankshaft drill** having a web thickness of 0.4*d* is used to drill deep

TABLE 3. SPEEDS AND FEEDS RECOMMENDED FOR DRILLS OF HIGH SPEED STEEL IN VARIOUS METALS WHEN CUT WITH A SUITABLE COOLANT

Size of Drill, in.	Feed per rev, in.	Bronze, Brass	Alloy Steel-Drop Forging	Cast Iron	Tool-Steel and Carbon-Steel Forgings	Mild Steel	Malleable Iron	Cast Steel	Hard Cast Iron
		fpm							
		300	50	140	60	120	90	40	80
		rpm							
1/16	0.003	18,320	3,056	8,554	3,667	7,328	5,500	2,445	4,889
1/8	0.004	9,160	1,528	4,278	1,833	3,667	2,750	1,222	2,445
3/16	0.005	6,106	1,019	2,852	1,222	2,445	1,833	815	1,630
1/4	0.006	4,575	764	2,139	917	1,833	1,375	611	1,222
5/16	0.007	3,660	611	1,711	733	1,467	1,100	489	978
3/8	0.008	3,050	509	1,426	611	1,222	917	407	815
7/16	0.009	2,614	437	1,222	524	1,048	786	349	698
1/2	0.010	2,287	382	1,070	458	917	688	306	611
5/8	0.011	1,830	306	856	367	733	550	244	489
3/4	0.012	1,525	255	713	306	611	458	204	407
7/8	0.013	1,307	218	611	262	524	393	175	349
1	0.014	1,143	191	535	229	458	344	153	306
1 1/8	0.015	1,017	170	475	204	407	306	136	272
1 1/4	0.016	915	153	428	183	367	275	122	244
1 3/8	0.016	833	139	389	167	333	250	111	222
1 1/2	0.016	762	127	357	153	306	229	102	204
1 5/8	0.016	705	118	329	141	282	212	94	188
1 3/4	0.016	654	109	306	131	262	196	87	175
1 7/8	0.016	610	102	285	122	244	183	81	163
2	0.016	571	95	267	115	229	172	76	153

holes $\frac{3}{16}$–$\frac{3}{8}$ in. diam. These thick-web drills are ground, Fig. 48, to break up the chips, and should operate at reduced speeds and feeds, as above.

Special drill shapes and **recommended speeds** are given in Table 4 for drilling a variety of materials. The Cincinnati-Bickford Co. developed the following speeds for sintered-carbide-tipped drills at light feeds: slate, 40 fpm; marble, 60–80; sandstone, 30; glass, 20–30; pure carbon, 100; and copper-graphite alloy, 60–70 (*American Machinist,* March 24, 1937, p. 271). They operate at 50 per cent higher speed than high speed steel drills. The point angle is 120 deg.

The time in minutes, t, for drilling a hole depends on the drill feed, f, in inches per revolution, the speed, n, in revolutions per minute, and the depth of hole drilled, H. The drill should travel $0.3d$ to cut full diameter and an added $0.2d$ if it breaks through to clean up the hole. The time to drill H inch is $t = \dfrac{H + 0.3d + 0.2d}{nf} = 1.08$ min for a $\frac{3}{4}$-in.-diam. drill to drill through a $3\frac{5}{8}$-in.-thick plate at 0.012-in. feed and 304 rpm (60 fpm).

Power Required in Drilling

The power at the point of the drill operating at given speed is made up of two factors, the torque and thrust.

The **torque, thrust,** gross and net power input from a series of tests (*SAE Journal*, March, 1931, p. 378) on annealed chrome-vanadium steel, SAE 6150, Brinell 187, and a soft cast iron, Brinell 163, are shown in Table 5.

To make it possible to determine the torque, T, thrust, B, or power for any other combination of diameter and feed, the following equations were determined from experiments in which the drill diameter, d, and feed, f, were varied separately.

$$\begin{aligned} &\text{For the steel,} \quad & T &= Cf^{0.78}d^{1.8} \quad \text{or} \quad & T_{6150} &= 1{,}840f^{0.78}d^{1.8} \\ & & B &= Kf^{0.78}d \quad \text{or} \quad & B_{6150} &= 53{,}400f^{0.78}d \end{aligned}$$

$$\begin{aligned} &\text{For the cast iron,} \quad & T_{CI} &= C_{CI}f^{0.6}d^2 \quad \text{or} \quad & T_{CI} &= 380f^{0.6}d^2 \\ & & B_{CI} &= K_{CI}f^{0.6}d \quad \text{or} \quad & B_{CI} &= 14{,}720f^{0.6}d \end{aligned}$$

A drill diameter of $1\frac{1}{2}$ in. and a feed of 0.015 in. give the following when drilling the SAE 6150 steel with a 1 to 16 emulsion $T_{6150} = 1{,}840 \times 0.0378 \times 2.074 = 144$ lb-ft, which corresponds to 143.3 lb-ft, Table 5. $B_{6150} = 53{,}400 \times 0.0378 \times 1.5 = 3{,}020$ lb, which is 20 lb higher than the experimental value in Table 5.

The equations for thrust are simplified, inasmuch as they do not consider a variation of web thickness to diameter. They are, however,

TABLE 4. DRILLING SPEED AND DRILL SHAPE FOR HIGH SPEED STEEL DRILLS CUTTING VARIOUS MATERIALS WITH A SUITABLE CUTTING FLUID

The values are given as a guide for setup purposes, to be altered as experience indicates. Feeds for fractional drill sizes are given in Table 3.

Type	Brinell Hardness	Point Angle, deg	Helix of Drill, deg	Cutting Speed, fpm	Cutting Fluid
Aluminum alloy		90*	30–45	300+	Em, Em and K
Bakelite, hard rubber, fiber, asbestos, etc.		60–90*	20–32	120	Em, D
Brass, leaded screw-stock		118	0‡	300	D, Em, MO
Brass, nonleaded		188	0‡	250	D, Em, MO
Bronze		118	0	200	D, Em, MO
Cast iron, soft	125	90	32	120	Em, A
Cast iron, medium hard	180	118	32	80	A, Em, D
Cast iron, chilled	512	136§	32‡	15‖	D
Copper		100	32	60+	Em, MO
Magnesium		120	22‡¶	500+	D, MO
Malleable cast iron		118	32	90	Em
Monel metal and nickel		118	32	50	S MO, Em
Steel, screwstock		118	32	180	Em, MO
Steel, stainless, free-cutting		118	32	130	Em, S MO
Steel, low-carbon (mild)	137	118	32	110	Em, S MO
Steel, medium-carbon	160	118	32	90	Em, S MO
Steel, high-carbon	164	118	32	50	Em, S MO
Steel, stainless 18-8		118	32¶	30‖	Em, S MO
Steel, castings	220	118	32	40	Em, S MO
Steel, forgings	250	125	32	80	Em, S MO
Steel, nitriding	250	118–140	32	40–50	S MO
Steel, 7 per cent manganese-steel rails	200–500	150	16‡	20	Em
Steel, 13 per cent manganese	200–500	136§	16‡	15‖	D
Slate		90	20(0†)	15(100†)	D
Zinc die castings		100	45¶	120	
Hard metals in general	350 up	150		40–50	

* Large polished flutes.

† WC tipped.

‡ Lip ground to zero rake as for brass.

§ Use a thick-web, cobalt-high speed steel drill, thinned at point.

‖ Lower feeds.

¶ Larger relief.

NOTE: A = Air suction.
D = Dry.
Em = Emulsion.
K = Kerosene.
MO = Mineral oil.
S MO = Sulphurized mineral oil.

reasonably accurate. The torque and thrust may be determined from the constants given in Table 6 for several other analyses of steel.

The **total net horsepower** developed at the drill point equals the horsepower due to the torque plus the horsepower due to the thrust as follows:

$$hp_c = \frac{2\pi Tn}{33{,}000} + \frac{Bfn}{12 \times 33{,}000}$$

To illustrate, the 1¼-in.-diam. drill with a feed of 0.015 in., rotating at 175.1 rpm (60 fpm) when cutting SAE 6150 steel, Table 5, has a torque of 110.8 lb-ft and thrust of 2,430 lb. Substituting these values in the above equation would give the total horsepower as follows:

$$hp_c = \frac{2\pi 110.8 \times 175.1}{33{,}000} + \frac{2{,}430 \times 0.015 \times 175.1}{12 \times 33{,}000} = 3.694 + 0.016$$
$$= 3.71$$

It is seen that the horsepower due to the thrust is only 0.016 or 0.44 per cent of the total power developed, so for power purposes the horsepower output due to the thrust may be neglected. It is of importance in design, however. Table 5 shows that the efficiency of the machine as determined by dividing the input by the output is highest when using small drills operating at high speed with resulting low values of torque and thrust. Similarly, the efficiency is lowest when the torque and thrust are high, even though the speed of the machine is less. It has been found that torque and thrust are affected but little by a change in cutting speed. The power, however, is a direct function of the speed, as illustrated above.

The **horsepower per cubic inch** of metal cut per minute is obtained by dividing the total net power at the cutter by the cubic inches of metal cut per minute, V. The formulas for SAE 6150 steel and cast iron become

$$\text{Unit } hp_c = (hp_c/V)6150 = \frac{0.446}{d^{0.2}f^{0.22}} \quad \text{and} \quad (hp_c/V)CI = \frac{0.092}{f^{0.4}}$$

The net horsepower per cubic inch of metal cut per minute, unit hp_c, is lower for larger values of feed and drill diameter. In drilling SAE 6150 steel with a ½-in.-diam. drill at 0.009-in. feed, a value of 1.443 is obtained. For drilling the same steel with a 1¼-in.-diam. drill at 0.015-in. feed, the unit hp_c is 1.075. For cast iron, these values are 0.605 and 0.493, respectively.

A small reduction in cutting speed often will permit an appreciable increase in feed without any sacrifice of tool life. For example, a ⅝-in.-diam. drill operating in SAE 1045 steel at 80 fpm (485 rpm) at

TABLE 5. TORQUE, THRUST, AND POWER IN DRILLING AN ANNEALED CHROME-VANADIUM STEEL, SAE 6150, AND A SOFT CAST IRON, USING AN EMULSION OF 1 PART SOLUBLE OIL TO 16 PARTS WATER*

Drill Diameter, in. d	Actual rpm N	Feed, in. per rev f	Torque, lb-ft T		Torque Horsepower hp_T	Thrust, lb B		Thrust Horsepower hp_B	Total Output, hp	Input, kw, from Wattmeter			Net Input, hp	Efficiency, per cent
			Test	Formula		Test	Formula			Gross	Tare	Net		
						Test Results on Steel, SAE 6150 Steel								
½	444.5	0.009	14.0	13.43	1.185	725	678	0.00732	1.193	1.6	0.67	0.93	1.244	96
⅝	368.0	0.011	22.3	23.4	1.562	838	990	0.00856	1.571	2.025	0.67	1.355	1.815	87
¾	299.7	0.012	34.3	34.8	1.957	1,269	1,273	0.01153	1.975	2.42	0.67	1.75	2.34	84
1	228.1	0.013	62.4	62.4	2.71	1,862	1,820	0.01394	2.724	3.176	0.57	2.606	3.49	78
1¼	175.1	0.015	110.8	104.0	3.694	2,430	2,520	0.01611	3.710	3.87	0.57	3.3	4.42	84
1½	149.0	0.015	143.3	144.0	4.07	3,000	3,020	0.01693	4.087	4.507	0.507	4.0	5.35	76
						Test Results on Cast Iron								
½	446.0	0.009	6.3	5.6	0.535	530	436	0.00614	0.541	1.12	0.67	0.45	0.602	90
⅝	364.4	0.011	10.2	9.9	0.708	645	615	0.00652	0.715	1.32	0.67	0.65	0.870	82
¾	299.7	0.012	15.7	15.05	0.896	803	778	0.00728	0.903	1.48	0.67	0.81	1.084	83
1	229.8	0.013	27.9	28.1	1.221	1,088	1,088	0.00822	1.23	1.72	0.50	1.22	1.635	75
1¼	179.4	0.015	46.4	47.8	1.585	1,403	1,481	0.00954	1.60	2.025	0.45	1.575	2.110	76
1½	153.4	0.015	65.9	68.7	1.925	1,700	1,778	0.00988	1.94	2.27	0.37	1.90	2.550	76

* Standard twist drills were used with 31-deg helix angle, 121-deg point angle, 136-deg chisel-edge angle, and 5-deg relief angle. The ratio of web thickness to diameter was 0.14 for the ¾ in. and larger drills, 0.162 for the ½-in.-diam. drills, and 0.185 for drills up to ⅜ in. diam. Speed 60 f.p.m.

TABLE 6. THE VALUES OF THE CONSTANTS C FOR TORQUE IN POUND-FEET AND K FOR THRUST IN POUNDS FOR SEVERAL ANALYSES OF STEEL IN THE FORM OF FORGINGS, NORMALIZED AND ANNEALED

T (torque) = $Cf^{0.78}d^{1.8}$. B (thrust) = $Kf^{0.78}d$.

SAE No.	Brinell	C	K
1020	137	1,590	40,000
1045	159	1,590	42,000
1095	154	2,180	69,000
2320	163	1,510	44,000
2330	202	1,780	66,000
2340	207	1,840	65,000
3120	143	1,510	39,000
3135	192	1,500	46,000
3250	207	1,740	57,000
3140	196	1,550	50,000
4130	156	1,560	43,000
6120	137	2,100	55,000
6130	156	2,000	56,000
6140	163	2,000	56,000
6150	187	1,840	53,400
9250	202	1,800	63,000

0.005 ipr gives a penetration of 2.4 ipm. If the speed is reduced to 60 fpm (370 rpm) and the feed increased to 0.010 ipr, the new penetration is 3.7 ipm. Thus, by decreasing the speed 25 per cent and doubling the feed, the penetration is increased by 50 per cent. The tool life was also increased.

In Fig. VII-22 are shown values of unit hp_c, obtained when drilling with a ¾-in. drill at 0.012-in. feed at 153 rpm, for a wide variety of metals, which give the following typical values: 0.2 for Dowmetal, 0.3 for aluminum alloy No. 12, 0.62 for cast iron, 0.9 for SAE 1112 steel, cold drawn to 1.4 for annealed carbon tool steel.

In another set of experiments [*Trans. ASME* (MSP), September, 1933, p. 1], each of a number of metals was drilled with eleven different types of cutting fluids. Formulas for torque and thrust for each metal are summarized in Table 7. The equations for torque for all steels agree with that for the steels given above. Each steel and cutting fluid has its own constant. Each other metal has its own formula. Because of the variation in ratio of web thickness to drill diameter, a more accurate formula for thrust was obtained for all steels as

$$B = Kf^{0.87}\left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$$

Values of torque for any drill diameter and feed may be obtained

TABLE 7. DRILLING TORQUE AND THRUST FORMULAS WITH CONSTANTS FOR TORQUE IN POUND-FEET AND THRUST IN POUNDS DETERMINED FROM DRILLING FERROUS AND NONFERROUS METALS WITH SEVERAL COMMONLY USED CUTTING FLUIDS*

Cutting Fluid Number	SAE 33 Aluminum Alloy $T = Cf^{0.85}d^{1.9}$ $B = Kf^{1.1}d^{1.2}$		Leaded Brass Screwstock $T = Cf^{0.73}d^{1.9}$ $B = Kf^{0.6}d^{1.0}$		Cast Iron $T = Cf^{0.6}d^{1.7}$ $B = Kf^{0.73}\left(\frac{d}{5}+\frac{w}{d}\right)^{1.9}$		Malleable Cast Iron $T = Cf^{0.86}d^{1.8}$ $B = Kf^{0.75}\left(\frac{d}{5}-\frac{w}{d}\right)^{1.75}$		SAE 3150 Steel		SAE 1020 Steel		SAE 1035 Steel		Carbon Tool Steel Annealed		SAE 1112 Steel	
									$T = Cf^{0.78}d^{1.8}$ $B = Kf^{1.57}\left(\frac{d}{5}+\frac{w}{d}\right)^{2.12}$									
	C	K	C	K	C	K	C	K	C	K	C	K	C	K	C	K	C	K
1	646	75,030	418	6,938	370	160,000	544	152,000	2.215	912,500	2.186	906,000	1.843	795,000	2.089	933,000	1,222	624,000
2	601	56,910	418	6,636	340	146,500	544	152,000	1.937	760,500	1.815	772,000	1.622	725,000	1,848	901,000	1,309	613,000
3	589	53,230	418	6,850	334	150,000	544	152,000	1.995	780,200	1,786	785,000	1.622	702,000	1,918	927,000	1,222	580,300
4	553	51,070	418	6,636	344	148,000	544	152,000	2,025	773,000	1.758	785,000	1,582	711,000	1.864	921,000	1,222	604,700
5	482	45,970	418	6,636	336	153,000	485	129,700	2.100	864,700	1,623	711,000	1,498	629,000	1,840	962,000	1.222	613,000
6	471	51,400	418	6,400	334	143,000	485	129,700	2,124	796,000	1,711	751,000	1.560	651,000	1,984	942,000	1,222	613,000
7	471	49,270	418	6,850	334	161,000	485	129,700	2.068	810,200	1,670	738,000	1.560	651,000	1,938	927,000	1,222	624,000
8	443	44,380	418	6.636	324	144,000	485	129,700	2.164	892,200	1,645	738,000	1.536	641,000	1.953	965,000	1,222	613,000
9	453	45,300	418	6,400	306	143,000	485	129,700	2.294	927,000	1,707	751,000	1.536	663,000	1.937	902,000	1,222	613,000
10	495	47,000	418	6,636	314	154,000	485	129,700	1.696	673,200	1.457	651,000	1.363	651,000	1.649	759,000	1.162	613,000
11	463	45,270	418	6,530	330	158,000	485	129,700	1.779	683,000	1.457	651,000	1.363	641,000	1.715	758,000	1.139	613,000
Kerosene	571	57,830																

* Actual values of torque and thrust for the 1¼-in.-diam. drill operating at a feed of 0.015 in. and a speed of 60 fpm (174 rpm) are plotted in Figs. 55 and 56, respectively. (See Table 5 for details of drills used.) The cutting fluids used are as follows:

1. Dry cutting.
2. Water containing 1½ per cent borax.
3. 1 part soluble oil to 50 parts water.
4. 1 part soluble oil to 10 parts water.
5. A No. 2 lard oil.
6. A light mineral oil.
7. A heavy mineral oil.
8. A light mineral oil containing 10 per cent lard oil.
9. A light mineral oil containing 5 per cent oleic acid.
10. A sulphurized mineral oil.
11. A sulphurized lard-mineral oil.

from the log-log graph, Fig. 53. The torque for a ¼-in. drill operating at 0.007-in. feed in the SAE 1020 steel is 3 lb-ft at T_1, the intersection of the horizontal line through the ¼-in. drill size and the vertical line through the 0.007-in. feed. T_2 represents 60 lb-ft, the torque developed by a 1-in. drill operating at 0.013-in. feed. The **torque for**

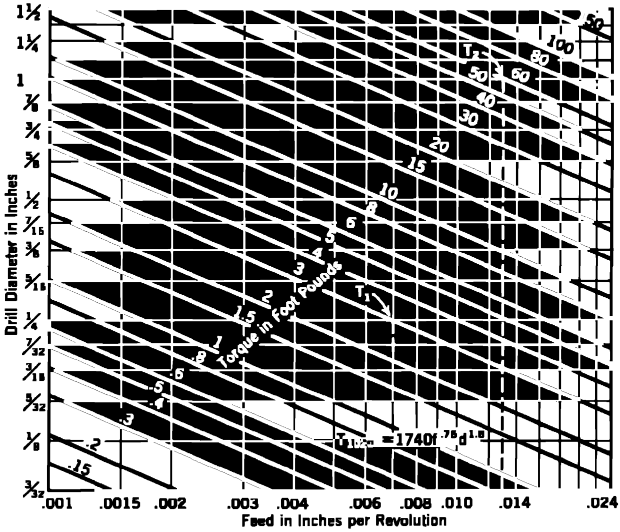


FIG. 53. Torque When Drilling Annealed SAE 1020 Steel with Commercial High-Speed Drills, Table 5, Using a 1 to 16 Emulsion, Plotted on Log-Log Coordinates as a Function of Drill Diameter and Feed.

other steels may be obtained by multiplying the value from Fig. 53 by the factors given in Table 8 (*Trans. ASME*, February, 1936, p. 79).

Values of thrust, as a function of drill diameter and feed, are shown on the log-log graph in Fig. 54. Because of a change in web thickness ratio at the ½-in. drill size, the lines in Fig. 54 are curved. Values of **thrust for other steels** may be obtained by multiplying the value from Fig. 54 by the constant shown in Table 8, or by computing from the formulas.

TABLE 8. FACTORS FOR OBTAINING TORQUE AND THRUST FOR OTHER STEELS FROM THOSE OF SAE 1020 STEEL, FIGS. 53 AND 54

SAE steel	1020	1035	0.97%C	3150	1112
Torque factor	1.00	0.90	1.06	1.15	0.69
Thrust factor	1.00	0.91	1.18	1.00	0.77

Effect of cutting fluids in drilling various metals: Formulas for torque and thrust have been determined for a variety of metals when using eleven cutting fluids which represent the various types commonly employed. The formulas, together with the constants, are listed in Table 7. Actual values of the torque for the 1¼-in.-diam. drill, operating at 0.015-in. feed per rev and a cutting speed of 60 fpm or 174 rpm, are plotted as a line for each metal over the cutting-fluid numbers arranged in increasing numerical order from left to right in Fig. 55. The corresponding values of thrust are similarly plotted in Fig. 56. The cutting fluid has no influence on the value of the torque, Fig. 55, when drilling the leaded brass screwstock. Only a slight variation in the thrust for the brass is shown in Fig. 56. From these figures, the cutting fluid giving the least torque or power and the least thrust can be selected readily. The greatest possible amount of fluid should be used.

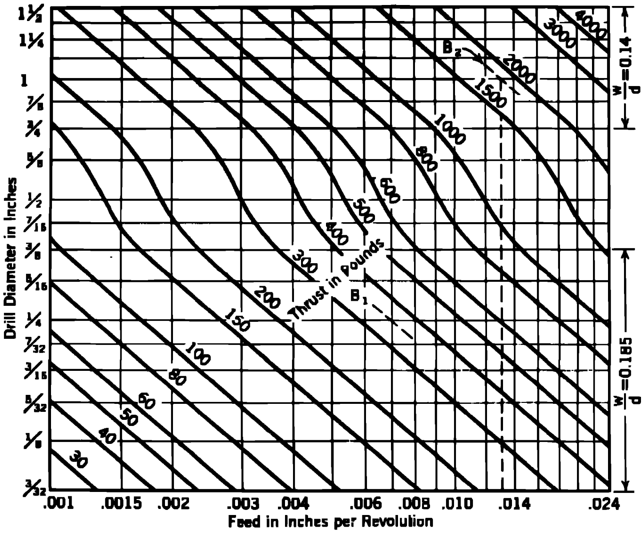


FIG. 54. Thrust When Drilling Annealed SAE 1020 Steel, as in Fig. 53, on Log-Log Coordinates.

Determining the formula for torque and thrust: The formula for torque and thrust is determined from the results of tests in which a given diameter drill is operated at various feeds for the first part, and drills of different diameters operated at the same feed for the second part. The results of such a series of experiments when drilling an annealed chromium-nickel steel corresponding to SAE 3150 are shown plotted in Fig. 57. The cutting speed was kept at 60 fpm for all drills. When plotting the torque values resulting from the 1-in.-diam. drill operating at feeds from 0.006 to 0.015 in., a straight line is obtained on log-log paper, which slopes at an angle from the horizontal whose tangent is 0.78. The experimental points for torque for the different diameter drills operating at constant feed also give a straight

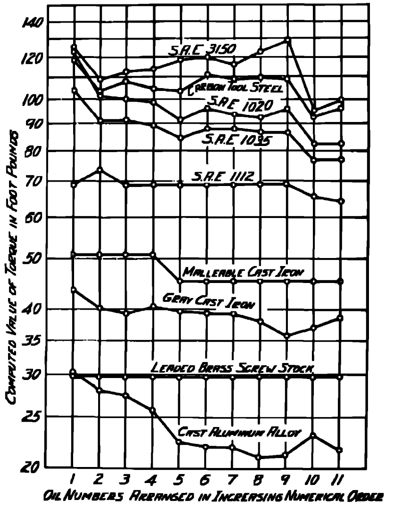


FIG. 55.

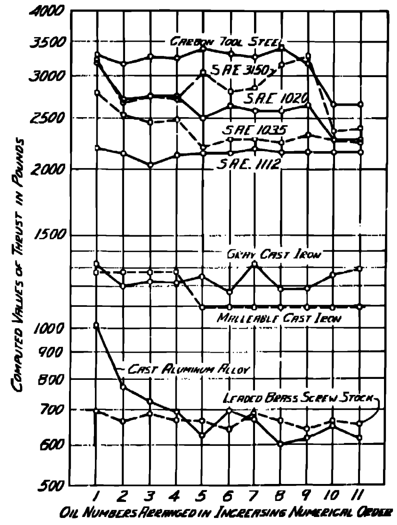


FIG. 56.

FIG. 55. Comparison of Torque Values for 1¼-in.-diam. Drills Operating at 0.015-in. Feed and 60 fpm Cutting Speed When Cutting Several Ferrous and Nonferrous Metals with Eleven Commonly Used Cutting Fluids.

Torque values are computed from equations and constants given in Table 7, where the cutting fluids are listed.

FIG. 56. Values of Thrust Corresponding to the Torque Values in Fig. 55.

line inclining from the horizontal at an angle whose tangent is 1.8. This gives rise to the equation, for torque as a function of variable feed and drill diameter, $T = Cf^{0.78}d^{1.8}$. By substituting the value of T for any given feed and drill diameter, the value of the constant C can be determined as 1,995 for cutting fluid No. 3.

Similarly, the values of thrust plotted as a function of feed for the constant drill diameter give a straight line, the slope from the horizontal of which is 0.87. The values of thrust as a function of the variable diameters working at constant feed of 0.009 in. give a slightly curved line which, when corrected for values of web thickness, give a straight line when plotted over $\left(\frac{d}{5} + \frac{w}{d}\right)$ at the right. The slope of this line is 2.12. The resulting equation for thrust is

$$B = Kf^{0.87}\left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$$

K is found to be 780,200 for cutting fluid 3 in Table 7. The key to the various symbols is shown in the title.

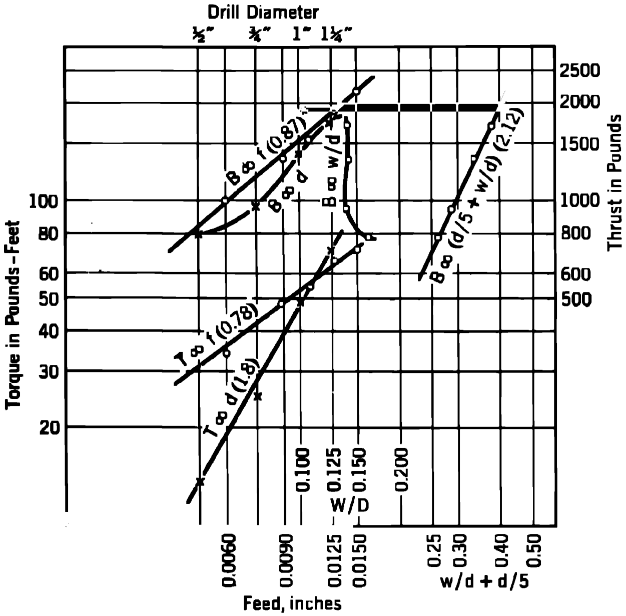


FIG. 57. Experimental Values of Torque and Thrust Required to Drill Annealed SAE 3150 Steel, Using Cutting Fluid No. 3 Consisting of 1 Part Soluble Oil to 50 Parts of Water.

* B is proportional to $f^{0.87}$.
See Table 5 for drills.

Performance of Drills

In general, drill performance is dependent upon many factors, such as:

1. Composition and treatment of drill.
2. Design of drill.
3. Grinding of point.
4. Speed.
5. Feed.

6. Depth of hole.
7. Diameter of hole.
8. Use and application of cutting fluid.
9. Material drilled.
10. Condition of machine, sleeves, chucks, and work-holding devices.

General recommendations are given for speeds, feeds, drill-point angle and helix, and cutting fluids in Tables 3 and 4 and Fig. 43. In general, the point angle is 118 deg and the relief is 6–8 deg.

If the peripheral speed of the drill is too high, the outer corners of the cutting edge will become overheated and wear away rapidly. Too much feed will cause the cutting edge to chip out, or if the feed is too much for the amount of lip relief, the chisel edge will be dulled quickly and the drill may split. Drill life is improved by rounding the corner.

Large drills, about 2 in. in diam., are not efficient, but are used principally for job work. When large holes are drilled, it is of advantage to drill a small hole first, as the thrust on the point is reduced 60 per cent by previously drilling a hole the diameter of the chisel edge, and the gross power is reduced about 10 per cent.

The drill feed for hard metals should be slightly less than the general recommendations. For drilling soft metals, the point angle is less and the feed may be increased above those normally specified. When drilling the hard metals, often extremely high pressures are required which may cause the drill lip to chip. This damage may be overcome either by the use of turpentine or kerosene to cause the drill to bite with less pressure, or by grinding the face of the cutting lip for a width of $\frac{1}{32}$–$\frac{1}{16}$ in. at zero rake. This same zero-rake tool may be used to advantage in drilling soft materials, such as brass, where the normal point has a tendency to dig in.

In drilling plastics a 60–90-deg included point angle is recommended with the face of the lip ground to a 0-deg rake, as is done for brass. The relief should be 10–12 deg, and large polished flutes should be provided. The small point angle is best for drilling sheets of plastic and metals so as to prevent drill breakage at the break-through and the lifting of the work at that time. Usually the drill cuts undersize. Drills tipped with carbide are most satisfactory, and speeds of 300–400 fpm are generally used.

When drilling through metal with small-diameter drills, the thrust is reduced as soon as the chisel edge breaks through the work. This may permit the weight of the spindle or the hand pressure to force the spindle forward suddenly, increasing the feed so that the lips take an unusually heavy cut. This heavy cut may cause the drill to break. Small point angles are helpful, and the corner at the margin may be chamfered or rounded. In general, small-diameter drills should operate at speeds higher than those recommended, rather than below. Very high speeds are best for drilling plastics. A small point angle, large polished flutes, and an air jet or stream of water prevent heating and clogging of the chips. Carbide-tipped and solid sintered-carbide drills are available for concrete, plastics, and abrasive materials.

BORING AND FACING TOOLS

Definition and Classification

A **boring** tool is used to enlarge an already existing opening. A **facing** tool, as covered in this discussion, is a tool used to face or spot-face the surface of work about an opening. Facing is sometimes combined with the operations of drilling, boring, or reaming.

A boring tool may consist of a **single point** forged on or clamped to a bar. These types are used in engine and turret lathes on jobbing and small-lot work to enlarge or true holes. **Double-end** boring tools which operate as flat drills also are used on turret lathes.

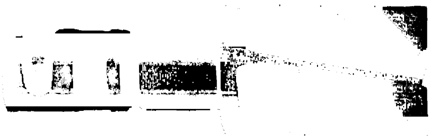
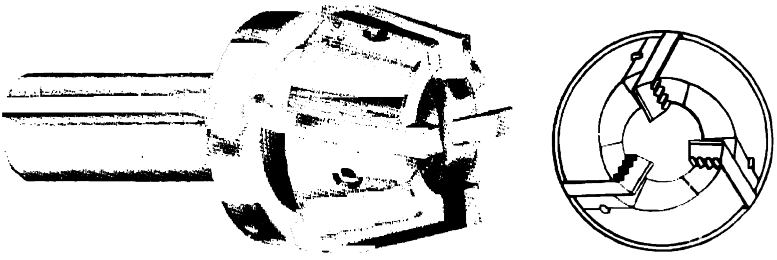


FIG. 58. A Side View of an Eclipse Standard Counterbore Cutter with Shank Interchangeable in a Holder as Shown in Fig. 62.

For production work where interchangeability, by virtue of long tool life per grind, is essential, the single-point tool is replaced by **multiple-cutting-edge boring tools.** The four-lip **core drill**, Fig. 49, sometimes is called a boring tool, as the operation performed is boring. An **end mill** (milling cutter) also is used for boring or counterboring. The latter is the reboring of a hole to a part of the whole depth. **Boring** and **counterboring** tools may be solid or have inserted blades; they may have integral taper shanks or be provided with a hole for arbor mounting. They also may have stub shanks which are interchangeable in holders which, in turn, fit the spindle of the drill press, Figs. 58 and 59. These cutters have through-holes which permit the assembly in the cutter of a pilot of any desired size, Fig. 60. The shanks of these cutters are ground cylindrical to fit with very close tolerances the opening in the holder. Where lengthwise adjustments of the cutter are desirable, as when facing, counterboring to specified depths, etc., an adjustable-length holder is provided, Fig. 61. A wide variety of combination of holders, cutters, and pilots may be obtained from standard sizes put up in sets as shown in Fig. 62.



Courtesy Gairing Tool Co.

FIG. 59. A General-Purpose, Adjustable-Blade, Hollow Mill.

The serrated blade is anchored in position and held by a hardened and ground steel wedge. The blade is adjusted radially by the serrations and axially by the supporting ring threaded on the body. The end view at the right shows three blades of the hollow mill set with a rake, as is used for steel, malleable iron, etc., but the rake would be zero when milling cast iron and brass.

The **independent-multiple-diameter boring tool**, Fig. 63, has been developed to overcome the shortcomings of the stepped counterboring tool. It has multiple lips for each diameter. The cylindrically ground margin of the leading ribs which do the boring give four points of support on the side of the wall of the hole for piloting the counterboring cutters of larger diameter following. Each cutting edge has an individual margin with a flute of sufficient size to take care of chip disposal.

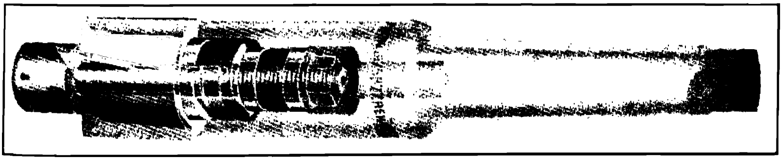


FIG. 60. An Assembly of an Eclipse Standard End Mill Cutter Having Interchangeable Shanks with a Pilot in the Standard Holder.

The pilot on the end of a through bolt is assembled with the cutter. This cutter-pilot assembly is then interchangeable in the holder with other assemblies.

Various types of adjustable **inserted-blade boring,** facing, or combination heads are in use. These heads, usually of a heat-treated alloy steel, are made to hold replaceable blades or bits (*American Machinist*, Aug. 2, 1933, p. 488). A **boring head** to hold interchangeable bits or blades is shown in Fig. 64. These blades may be of any desired tool

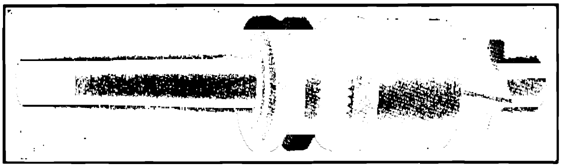
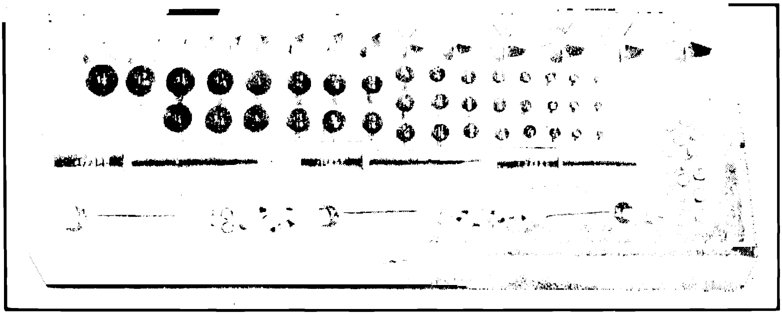


FIG. 61. The Eclipse Improved Quick-Adjustable Stop-Collar Holder.

This holder, taking the interchangeable cutter shanks, is recommended for use when counterboring, spot-facing, countersinking, or core drilling to a specified depth. Quick adjustment of the collar up or down may be accomplished by hand by slackening the lock nut, lifting the serrated collar which is keyed to the shank, and turning the serrated holder on the shank to any desired position, after which the serrated collar is locked in place by the knurled nut.



Courtesy Gairing Tool Co.

FIG. 62. The Gairing No. 4B Counterbore Set, Consisting of Cutters ⅜ in. diam. to 2 in., Pilots ¼ in. to 1¼ in., and Countersinks of 82 and 70 deg.

The assembly of counterbore, pilot, and nut fits interchangeably in one of the three holders which have Morse tapers to fit the spindle of a drill press or milling machine adapter.

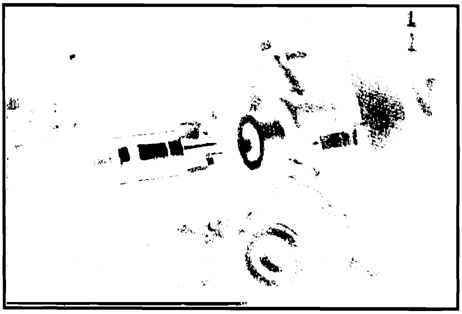


FIG. 63. An Eclipse Multiple-Diameter Combination Cutter.

It is used for core drilling, chamfering, counterboring, and finish facing a water-pump housing in a turret lathe. The cutter is made from solid high speed steel and performs all the operations at one pass.

material. Where the diameter is to be maintained, the blades are adjustable radially outward as the cutter is worn or reground, the principal wear being on the outer corner. The serrations in the back of the blades fit corresponding broached serrations in the body. The **facing head,** resembling the end mill, has replaceable blades which may be moved forward at right angles to those of Fig. 64 as the blades are reground in the diametral plane where most wear occurs. Cutters of this type are made **multiple** or in combination so that different diameters can be bored, or diameters bored and surfaces faced simultaneously.

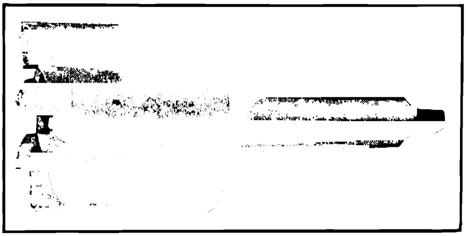


FIG. 64. The O.K. Tool Co. Series 700 Inserted-Blade Adjustable Boring Head with Integral Taper Shank.

Hollow mills or solid or adjustable-blade type, Fig. 59, are used for forming external surfaces, as the multiple-blade boring tools form internal surfaces.

Torque, Thrust, and Power

Values of torque, T, thrust, B, horsepower at the cutter, hp_c, and values of K_1 and K_2 are given in Table 9 for each of the several materials, as developed by a counterbore with cutter diameter, $D_c = 1\frac{1}{4}$ in., pilot diameter, $D_p = \frac{1}{2}$ in., $n = 3$ lips, feed $f = 0.001$ ipt, speed $V = 189$ fpm when cutting dry. The counterbore is tipped with sintered carbide and has a radial rake angle of 0 deg and an axial rake of +3 deg.

All metals produce the same formula except for differences in the constants. High speed steel cutters will give about the same values. The factors are the ratio of the torque or thrust of any material to that of the SAE 1020 steel. The general formulas for T, B, and hp_c are as follows:

$$T = K_1 nf(D_c^2 - D_p^2)$$

$$B = K_2 nf \frac{(D_c - D_p)}{2}$$

$$hp = \frac{2\pi N K_1 nf(D_c^2 - D_p^2)}{33{,}000} = \frac{2\pi NT}{33{,}000}$$

Table 9. Values of Torque, Thrust, and Power for Counterboring Various Metals with a 3-Lip, Carbide-Tipped Tool of 1¼-in. D_c and ½-in. D_p Operating at 0.003 ipr and 189 fpm, Cutting Dry

Material Cut	Bhn.	Torque, T			Thrust, B			hp_c
		lb-ft	K_1	Factor	lb	K_2	Factor	
SAE 1020 steel, cold drawn	180	16.5	4,130	1.0	258	233,000	1.0	1.81
SAE 6150 steel, hot rolled	195	21.9	5,540	1.33	445	401,000	1.72	2.41
SAE 6150 steel, heat treated, HR	241	35.0	8,760	2.12	540	487,000	2.09	3.84
Tool steel, 1% C, annealed	156	31.0	7,770	1.88	785	709,000	3.04	3.4
Cast iron, 40,000 psi	210	14.0	3,515	0.85	180	165,400	0.71	1.54
Monel metal	207	32.0	8,020	1.94	350	317,000	1.36	3.52
Phos. bronze	156	12.5	3,140	0.76	210	191,000	0.82	1.37
Leaded brass	124	6.2	1,570	0.38	54	48,900	0.21	.68
Aluminum alloy, 24 ST	154	8.9	2,230	0.54	210	191,000	0.82	.98
Aluminum 2S, soft	36.6	23.0	5,740	1.39	695	630,000	2.70	2.53
Magnesium cast H-alloy	63.4	4.1	1,033	0.25	69	63,000	0.27	.45

REAMERS

Definition and Classification

A reamer is a tool used for enlarging or finishing a hole previously drilled, bored, or cored, to give a good finish as well as accurate dimensions.

There are various classifications of reamers based upon operation, purpose, and shape, as follows:

1. Hand reamers.
2. Taper-shank jobbers' reamers.
3. Chucking or machine reamers.
4. Shell reamers.
5. Center reamers.
6. Taper reamers.
7. Expansion reamers.
8. Adjustable reamers.
9. Special reamers.

Hand reamers have square tangs and are driven by hand for sizing and perfecting holes. They may be straight or helical fluted, Fig. 65. They are designed to remove but a few thousandths of an inch of metal, and are slightly tapered for the first third of the body length to facilitate their starting properly. They are not end-cutting tools, but rather cut along the longitudinal cutting edges. The diameter of the shank is ground 0.005 in. undersize.

A **threaded-end** hand reamer has fluted threads for a short distance at the point. These threads give a uniform feed to the tool when reaming.

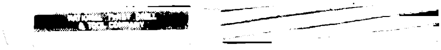


FIG. 65. Jobbers' Hand Reamer with Helical Flutes.

These are side-cutting or sizing reamers.

The **taper-shank jobbers'** reamers are of the same design as hand reamers, with the exception of the shank, which is tapered for machine use, and the fact that the cutting edges are not tapered on the end.

Chucking or **machine** reamers are used on machine tools such as drill presses, turret lathes, and screw machines. The tool may have a

FIG. 66. Rose Chucking Reamer with Straight Flutes and Taper Shank.

This is an end-cutting reamer with wide lands ground cylindrically.

taper shank; a straight shank, usually with a flat to engage the driving setscrew; or a special type. Chucking reamers are divided into two types: the fluted and rose. The **rose** chucking reamer, with eccentric flutes and taper shank, Fig. 66, is designed to take heavy cuts on the end. For this reason it has no radial relief on the margin, but is provided with a back taper of about 0.002 in. per ft. Rose reamers

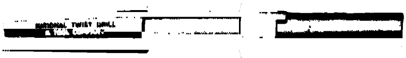


FIG. 67. Morse Taper-Shank Arbor for Shell Reamers.

are particularly adapted for reaming cored holes. **Fluted** chucking reamers are side cutting like the jobbers' reamer and are used in machines for taking light cuts as in finishing rose-reamed or bored holes to size. Best results are obtained when the reamer floats, which permits it to align itself with the hole and ream the hole true to standard size. The margins of fluted reamers are cylindrical for a width of only a few thousandths of an inch. Large reamers are provided as shells to keep the cost of the tool material low. The shells are interchangeable with arbors, Fig. 67, so that in the job shop, only one arbor is needed for a variety of shell sizes; or in production work, the worn-out shell may be replaced. Shell reamers may be either of the **rose chucking** type for truing the hole, Fig. 68, or the **fluted** type for finishing, Fig. 69. The fluted type may be made with straight or helical flutes. When helical, the cutting edges are tilted forward, rather than backward, as in the case of a twist drill. These reamers should be used in a full-floating holder so the reamer will align with the work to produce accurate and straight holes.

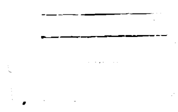


Fig. 68. Rose Shell Reamers with Straight Flutes.

This is an end-cutting machine reamer. The lands back of the cutting edge are cylindrical.

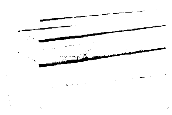


Fig. 69. A Shell Fluted Reamer with Helical Flutes.

This is a side-cutting reamer for light finishing cuts. Also made with straight flutes.

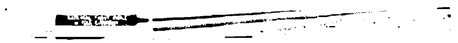


Fig. 70. Helical Fluted Taper-Pin Reamer Having ¼ in. per ft Pitch.

It is made in sizes from No. 1, having a diameter of 0.146 at the small end, an over-all length of 2½ in. and length of flute of 1¾ in., to No. 12, having a diameter at the small end of 0.842 in., an over-all length of 13⅜ in., and a length of flute of 10 in.

Center reamers, consisting of a small straight-shank tool with a 60-deg point, are used for reaming the center holes of work held on centers, and also for counterboring for screwheads. There are two types, the first having but one cutting edge in which one-half of the conical point is removed, and the second usually having four flutes. Center reamers having 72- or 82-deg angles also are furnished.

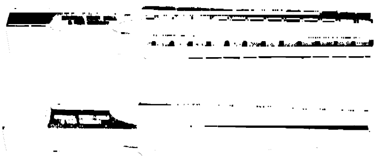


Fig. 71. Roughing and Finishing Reamers for Finishing Morse Taper Sockets.

These reamers are made for Morse tapers No. 0 to 6, incl. The blades of the roughing reamer are alternately notched to break up the chips. A similar set for reaming Brown and Sharpe tapers for Nos. 1 to 12, incl., also is provided.

Taper reamers are used for reaming tapered holes. There are various classes of taper reamers, depending upon their use. They are made with straight flutes, Fig. 71, or with helical flutes, Fig. 70. The **taper-pin** reamers, Fig. 70, having a taper of ¼ in. per ft, are used for reaming holes for self-locking taper pins. The point of each reamer will enter the hole reamed by the next size smaller.

Roughing and **finishing** reamers for finishing standard taper sockets, Fig. 71, are made with the Morse, Brown and Sharpe, or Jarno standard taper. Other taper reamers are made, such as **locomotive** taper reamers with square or taper shanks having a taper of $\frac{1}{16}$ in. per ft.; taper **bridge** reamers with straight or helical flutes for use in reaming the rivet and bolt holes in structural iron or steel, boiler plate, and similar work; and **pipe** reamers, with a taper of $\frac{3}{4}$ in. per ft. for reaming holes in pipe to be tapped.

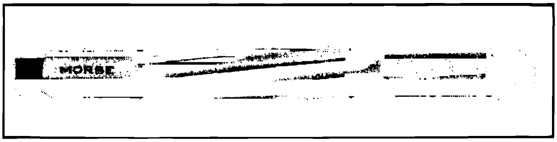
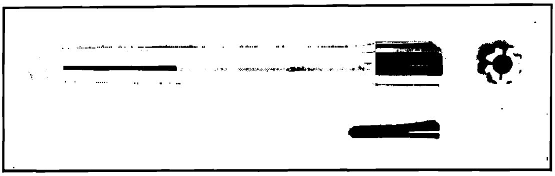


FIG. 72. Expansion Hand Reamer.

An adjustment of several thousandths of an inch on the diameter is made possible by expanding internal cones.

The **expansion** reamers, Fig. 72, are designed primarily for job-shop or repair work where it is necessary to enlarge reamed holes but a few thousandths of an inch. A production expansion chucking reamer, Fig. 73, after being worn undersize, may be expanded by the taper plug and reground to the original size.



Courtesy Morse Twist Drill and Machine Co.

FIG. 73. An Expansion Machine Reamer with Morse Taper Shank.

Adjustable reamers are those provided with adjustable cutting blades as an integral part of the reamer. They have cutting edges on attached or inserted blades, and permit variation in size or give increased life to the reamer, as the worn blades may be adjusted and reground to the original size.

The Gisholt Machine Co. shell reamer with high speed steel attached blades is designed for turret-lathe work. Blades are made in three types, with a right-hand helix for heavy roughing, with a left-hand helix for smooth accurate finishing, or with a double-fluted straight blade for general finishing. These blades are interchangeable on one body which should be supported on full-floating bars. By placing shims under the blades, the dull reamer can be reground to its original size.

In the **adjustable** reamer, the blades may be moved forward and locked into position between two lock collars operated by a spanner wrench. This forward motion also increases the diameter of the reamer. This permits the blades to be reground a number of times, after which a new set of blades can be inserted in the hardened-steel body.

For roughing work, particularly on tough steel, a positive rake or right-hand helix is desirable. For general work and for semifinishing, straight blades prove satisfactory; but for finish reaming, the negative rake or left-hand blade often gives best results.

Reaming Speeds and Feeds

In machine reaming, the peripheral **speed** should be about one-half of that designated for a drill of the same size and material. The **stock of metal** on the diameter of the hole, to be removed by a finishing reamer, should be about two-thirds, or less, of the feed of a drill of that size. In production work, this is kept as small as will clean up to give the best finish and greatest life of the reamer. For some machine reamers, from 0.002 to 0.006 in. is allowed. In job-shop work, where standard jobbers' or fractional-size drills are used to prepare the hole for the reamer, $1/64$ in. is the smallest increment. This may make it necessary to drill, rose-ream, and then flute-ream.

Reaming is best accomplished in production by using tools of the expansion or adjustable type with relatively low speeds but high feeds. Less material should be removed in reaming plastics than when reaming other materials.

The **feed** of the rose reamer should be two to three times and that of the fluted reamer three to five times as great as the feed specified for a drill of that size, depending upon the material being reamed, the accuracy and finish desired, and other operating conditions, such as the number of cutting edges in the reamer and the metal cut. If the reamer chatters, reduce the speed and increase the feed.

In reaming **aluminum** and its alloys, the negative helical fluted type of reamer produces by far the best results. In reaming **Monel metal,** a high speed steel helical fluted reamer with a slow speed of 10–15 fpm should be used, while the tool is fed slowly into the work. The duplex helical taper reamer, developed by the Pratt and Whitney Co. for use on tough alloys, is very satisfactory for work on Monel metal. It has two sets of four flutes, each set with slightly different helix angles. This tends to overcome chatter and produces a true smooth surface.

Cutting Fluids Used in Reaming

Cast iron is reamed dry. A cutting fluid improves the results when reaming **aluminum.** An emulsion is often used, but kerosene or kerosene mixed with lard oil in equal parts is found best under certain conditions. A little turpentine is sometimes added to the last-named mixture. Paraffin-base mineral oils, generally used on **brass,** are not suitable for aluminum. Medium-hard **bronze** reams well with a light mineral oil, while hard bronze responds well to the cutting fluids recommended for steel.

In reaming **steel,** a mineral-lard oil or sulphurized lard-mineral oil is most generally used for fluted reamers. A mineral-lard of 70 per cent mineral and 30 per cent lard oil, or equal proportions, is sometimes necessary for hard steels. For rose reamers, emulsions may be used for general work.

THREADING TOOLS

Forms of Screw Threads

Threading tools must be formed to cut threads of several different shapes, such as the American Standard (National Coarse and Fine series), V, Acme, square, pipe, Whitworth, buttress, Dardelet.

The simple theoretical **V thread** is formed by cutting a helical V-shaped section from the periphery of a cylinder. The included angle between two adjacent faces is 60 deg. and the crest of the thread and the root of the V are cut to sharp points, as shown by the light dashed lines in Fig. 74*A*. The depth of the thread equals the pitch times 0.866025. While this form of thread is simple to cut, requiring only a V-point tool, it is easily damaged and weakens the threaded bar because of its greater depth and sharpness of root.

The **American (or National) Standard thread form** is similar to the V thread except that the crest of the thread and the root of the groove are made flat, Fig. 74*A*. This form of thread has been used almost universally in this country, but is now superseded by the **Unified series** adopted by England, Canada, and the United States. These are described below and illustrated in Fig. 77. For small-numbered sizes below ¼ in., these threads are known as the American Society of Mechanical Engineers **(ASME)** coarse and fine series **machine screw threads,** as listed in Table 10. For the fractional sizes ¼ in. diam. and larger, they are known as the **National Coarse** (NC) series thread, and the **National Fine** (NF) series thread, Table 11. The *American Standard Screw Threads* (ASA B1.1, 1938) for bolts, machine screws, nuts, and commercially tapped holes give all definitions and the tolerances for various fits, such as loose fit, free fit, medium fit, and close fit. The basic size from which tolerances and allowances are made is the pitch diameter of the nut. The allowances are zero for the free and medium fits and slightly negative, causing interference, for the close fit. This latter, therefore, requires selective assembly.

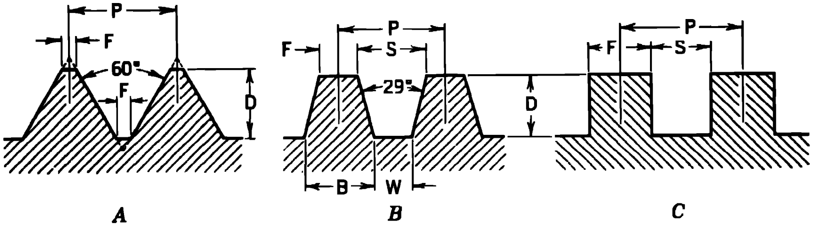


Fig. 74A. American (National) Form of Screw Thread.

This is used in coarse and fine series, as well as the ASME machine-screw size below ¼ in.

P = pitch = $1/N$. D = depth = pitch × 0.649519 = $0.649519/N$.

N = threads per inch. F = flat = pitch/8.

Fig. 74B. The Acme 29-deg Screw Thread.

N = threads per inch. W = width of point of tool for screw thread = $0.3707/N - 0.0052$.

F = width of screw or nut thread = $0.3707/N$.

The depth of screw at root = $1/2N + 0.010$.

Bore of nut = nominal major diameter − (double depth of thread + 0.020).

Diameter of tap = nominal major diameter + 0.020.

Fig. 74C. The Square Screw Thread.

F = flat width = $P/2$. D = depth = $P/2$.

P = pitch = $1/N$. S = space width = $P/2$.

The **Acme 29-deg screw thread,** Fig. 74B, is made with 1–10, incl., threads per in. It is an adaptation of the most commonly used style of worm thread and is intended to take the place of the square thread. It is a little shallower than the worm thread, but the same depth as the square thread.

The **square thread,** Fig. 74C, as the name implies, has a square-sectioned screw thread, the face of which equals the space and depth. These threads, cut on a lathe, employ a square-ended tool with no side rake but ample side relief. When cutting internal square threads as in a nut, the width of the square-ended tool is from 0.001 to 0.003 in. oversize to permit clearance between the nut thread and the screw thread. Also, the depth of the nut thread is made a few thousandths of an inch deeper than that of the screw thread for radial clearance. A lathe tool must be ground carefully for cutting Acme and square threads in order to provide sufficient side relief. The flank of the tool, instead of being vertically beneath the face, is inclined to one side equal to the angle of helix of the thread. Side relief then

Table 10. Machine Screws — Numbered Sizes*

	Size of Screw	Threads per Inch	Major (Outside) Diameter, Maximum	Minor (Root) Diameter, Maximum	Tap Drill Diameter
Coarse thread series	1	64	0.0730	0.0538	0.0595
	2	56	0.0860	0.0641	0.0700
	3	48	0.0990	0.0734	0.0785
	4	40	0.1120	0.0813	0.0890
	5	40	0.1250	0.0943	0.1015
	6	32	0.1380	0.0997	0.1065
	8	32	0.1640	0.1257	0.1360
	10	24	0.1900	0.1389	0.1495
	12	24	0.2160	0.1649	0.1770
Fine thread series	0	80	0.0600	0.0447	0.0469
	1	72	0.0730	0.0560	0.0595
	2	64	0.0860	0.0668	0.0700
	3	56	0.0990	0.0771	0.0820
	4	48	0.1120	0.0864	0.0935
	5	44	0.1250	0.0971	0.1040
	6	40	0.1380	0.1073	0.1130
	8	36	0.1640	0.1299	0.1360
	10	32	0.1900	0.1517	0.1590
	12	28	0.2160	0.1722	0.1820

* American (National) Standard coarse and fine thread series — based upon the free fit, class 2 screws. The tap drill sizes are commercial sizes based upon 75 per cent of standard thread depth. Thread form shown in Fig. 74A.

should be provided on each side of the flank. This is illustrated by the right- and left-hand Acme threading tools, Nos. 6 and 7, in Fig. V-6.

The **Whitworth thread** was the standard in England. It is a modification of the V thread. The included angle between two adjacent faces is 55 deg, and the crest of the tooth and root of the V are rounded with a radius equal to 0.1373 times the pitch. The depth of the tooth is 0.64033 times the pitch. It is now superseded by the Unified series.

A **buttress thread** has a face at right angles to the axis of the screw on one side and a 45-deg bevel on the other side. This thread is very strong and efficient when taking an axial load on the radial face of the tooth.

The **International Metric standard thread,** generally used in France, has the same form and proportion as the American Standard. The **American** (Briggs) Standard pipe thread, Fig. 75, has a V form of thread, but tapers $\frac{3}{4}$ in. per ft or $\frac{1}{16}$ in. per in., Table 12.

TABLE 11. BASIC DIMENSIONS OF THE UNIFIED COARSE AND FINE THREAD SERIES

Unified Coarse Thread Series

Sizes	Basic Major Diameter, inches	Threads per Inch	Basic Pitch Diameter,* inches	Minor Diameter, ext. thds., inches	Minor Diameter, int. thds., inches	Lead Angle at Basic Pitch Diameter, deg	min	Tap Drill Size
	D	n	E	K_s	K_n	λ		
1/4	0.2500	20	0.2175	0.1887	0.1959	4	11	0.2031
5/16	0.3125	18	0.2764	0.2443	0.2524	3	40	0.2570
3/8	0.3750	16	0.3344	0.2983	0.3073	3	24	0.3125
7/16	0.4375	14	0.3911	0.3499	0.3602	3	20	0.3680
1/2	0.5000	12	0.4459	0.3978	0.4098	3	24	0.4219
9/16	0.5625	12	0.5084	0.4603	0.4723	2	59	0.4844
5/8	0.6250	11	0.5660	0.5135	0.5266	2	56	0.5312
3/4	0.7500	10	0.6850	0.6273	0.6417	2	40	0.6562
7/8	0.8750	9	0.8028	0.7387	0.7547	2	31	0.7656
1	1.0000	8	0.9188	0.8466	0.8647	2	29	0.8750
1 1/8	1.1250	7	1.0322	0.9497	0.9704	2	31	0.9844
1 1/4	1.2500	7	1.1572	1.0747	1.0954	2	15	1.1094
1 3/8	1.3750	6	1.2667	1.1705	1.1946	2	24	1.2187
1 1/2	1.5000	6	1.3917	1.2955	1.3196	2	11	1.3437
1 3/4	1.7500	5	1.6201	1.5046	1.5335	2	15	1.5625
2	2.0000	4 1/2	1.8557	1.7274	1.7594	2	11	1.7812
2 1/4	2.2500	4 1/2	2.1057	1.9774	2.0094	1	55	2.0312
2 1/2	2.5000	4	2.3376	2.1933	2.2294	1	57	2.2500
2 3/4	2.7500	4	2.5876	2.4433	2.4794	1	46	2.5000
3	3.0000	4	2.8376	2.6933	2.7294	1	36	2.7187
3 1/4	3.2500	4	3.0876	2.9433	2.9794	1	29	2.9687
3 1/2	3.5000	4	3.3376	3.1933	3.2294	1	22	3.1875
3 3/4	3.7500	4	3.5876	3.4433	3.4794	1	16	3.4375
4	4.0000	4	3.8376	3.6933	3.7294	1	11	3.6875
Unified Fine Thread Series								
1/4	0.2500	28	0.2268	0.2062	0.2113	2	52	0.2131
5/16	0.3125	24	0.2854	0.2614	0.2674	2	40	0.2720
3/8	0.3750	24	0.3479	0.3239	0.3299	2	11	0.3320
7/16	0.4375	20	0.4050	0.3762	0.3834	2	15	0.3906
1/2	0.5000	20	0.4675	0.4387	0.4459	1	57	0.4531
9/16	0.5625	18	0.5264	0.4943	0.5024	1	55	0.5156
5/8	0.6250	18	0.5889	0.5568	0.5649	1	43	0.5781
3/4	0.7500	16	0.7094	0.6733	0.6823	1	36	0.6875
7/8	0.8750	14	0.8286	0.7874	0.7977	1	34	0.8125
1	1.0000	12	0.9459	0.8978	0.9098	1	36	0.9375
1 1/8	1.1250	12	1.0709	1.0228	1.0348	1	25	1.0469
1 1/4	1.2500	12	1.1959	1.1478	1.1598	1	16	1.1719
1 3/8	1.3750	12	1.3209	1.2728	1.2848	1	9	1.2969
1 1/2	1.5000	12	1.4459	1.3978	1.4098	1	3	1.4219

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* British: Effective diameter.

TABLE 12. AMERICAN STANDARD PIPE THREADS WITH LOCK-NUT THREADS AND BASIC STRAIGHT PIPE SIZES*

Pipe Size, inches	Threads per Inch N	Outside Diameter Pipe, inches D	Total Length of Thread, inches H	Tap Drill Size†
⅛	27	0.405	0.3749	0.339
¼	18	0.540	0.5685	7/16
⅜	18	0.675	0.5745	37/64
½	14	0.840	0.7480	23/32
¾	14	1.050	0.7600	59/64
1	11½	1.315	0.9437	1 5/32
1¼	11½	1.660	0.9677	1½
1½	11½	1.900	0.9844	1 47/64
2	11½	2.375	1.0174	2 7/32
2½	8	2.875	1.5125	2⅝
3	8	2.500	1.5750	3¼
3½	8	4.000	1.6250	3¾
4	8	4.500	1.6750	4¼
4½	8	5.000	1.7250	. . .
5	8	5.563	1.7813	. . .
6	8	6.625	1.8875	. . .
8	8	8.625	2.0875	. . .
10	8	10.750	2.3000	. . .
12	8	12.750	2.5000	. . .

* For pipe-thread drawing, see Fig. 75.

† Tap drill sizes given permit of direct tapping without reaming the hole beforehand.

The **Dardelet** thread resembles the Acme thread in shape, but the thread depth is less, and the root of the thread on the screw and the crest of the thread in the nut are tapered about 6 deg. The space between the threads is about 60 per cent greater than the thread width, so considerable end play is provided. As the nut is tightened on the bolt, the tapered surfaces lock. This combines self-locking and very great strength.

The **Unified Screw Thread** Standard is shown in Figs. 76 and 77 for the internal thread (nut) and the external thread (screw). The minimum, major, pitch, and minor diameters of the internal thread are respectively the same for three classes: 1B, 2B and 3B. The tolerance on the internal thread is plus from the basic size. The tolerance on the external thread is minus from the maximum size. The basic formula from which allowances on all diameters and tolerances on pitch diameters are derived is:

$$\text{Tolerance (or allowance)} = C(0.0015\sqrt[3]{D} + 0.0015\sqrt{L_e} + 0.015\sqrt[3]{p^2})$$

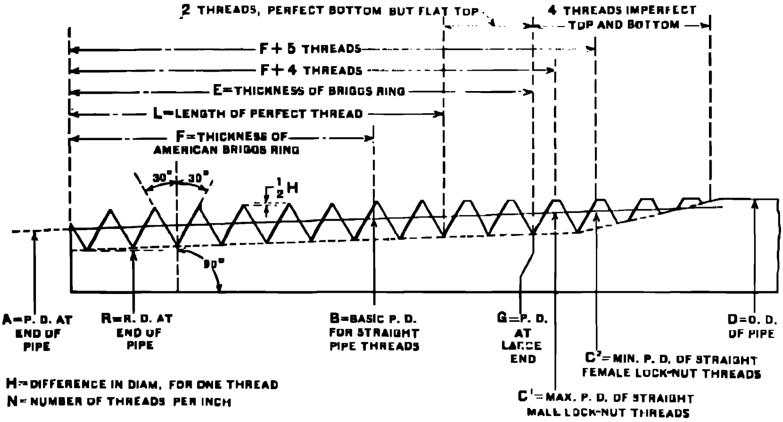

2 THREADS, PERFECT BOTTOM BUT FLAT TOP
4 THREADS IMPERFECT TOP AND BOTTOM
F + 5 THREADS
F + 4 THREADS
E = THICKNESS OF BRIGGS RING
L = LENGTH OF PERFECT THREAD
F = THICKNESS OF AMERICAN BRIGGS RING
30°
30°
1/2 H
90°
A = P. D. AT END OF PIPE
R = R. D. AT END OF PIPE
B = BASIC P. D. FOR STRAIGHT PIPE THREADS
G = P. D. AT LARGE END
D = O. D. OF PIPE
C² = MIN. P. D. OF STRAIGHT FEMALE LOCK-NUT THREADS
C¹ = MAX. P. D. OF STRAIGHT MALE LOCK-NUT THREADS
H = DIFFERENCE IN DIAM. FOR ONE THREAD
N = NUMBER OF THREADS PER INCH

Fig. 75. The American (Briggs) Standard Pipe Thread with Lock-Nut Threads and Basic Straight Pipe Sizes.

This thread consists of a sharp V thread cut on the taper of ¾ in. on the diam. per ft, the normal engagement by hand between external and internal threads. See Table 11.

P = pitch of thread = $1/N$. $A = D - (0.05D + 1.1)P$.

Depth of thread = $0.80P$. $B = A + 0.0625F$.

$$E = (0.080D + 6.8)P.$$

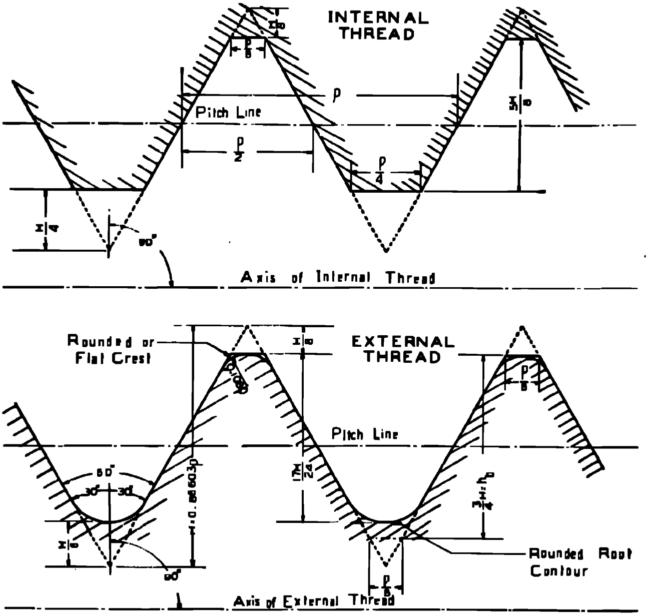


Fig. 76. The Unified Internal and External Screw Thread Design Forms (Maximum Metal Condition).

in which C is a factor which differs for each tolerance or allowance for each class, D is the basic major diameter, L_e is the length or engagement, and p is the pitch. The above threads are interchange-

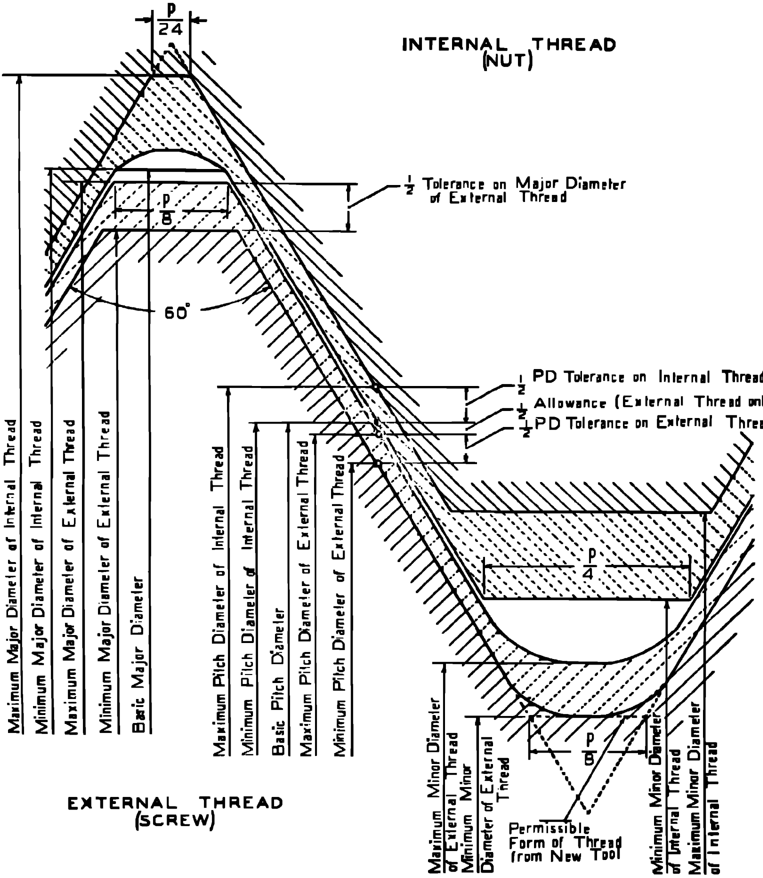

$\frac{p}{24}$
INTERNAL THREAD (NUT)
$\frac{1}{2}$ Tolerance on Major Diameter of External Thread
$\frac{p}{8}$
60°
$\frac{1}{2}$ PD Tolerance on Internal Thread
$\frac{1}{2}$ Allowance (External Thread only)
$\frac{1}{2}$ PD Tolerance on External Thread
$\frac{p}{4}$
Maximum Major Diameter of Internal Thread
Minimum Major Diameter of Internal Thread
Maximum Major Diameter of External Thread
Minimum Major Diameter of External Thread
Basic Major Diameter
Maximum Pitch Diameter of Internal Thread
Minimum Pitch Diameter of Internal Thread
Basic Pitch Diameter
Maximum Pitch Diameter of External Thread
Minimum Pitch Diameter of External Thread
EXTERNAL THREAD (SCREW)
Maximum Minor Diameter of External Thread
Minimum Minor Diameter of External Thread
$\frac{p}{8}$
Permissible Form of Thread from New Tool
Minimum Minor Diameter of Internal Thread
Maximum Minor Diameter of Internal Thread

FIG. 77. Disposition of Tolerances, Allowances, and Crest Clearances for Unified Classes 1A, 2A, 1B, and 2B.

The drawing is the same for tolerances and crest clearances for Unified Classes 3A and 3B except that the allowance is zero.

able with the American National threads. The allowance is applied only to external threads for which the factor C equals 0.300 for Class 1A and 2A and zero for Class 3A. The values of C for pitch-diameter tolerances are as follows: 1A, 1.500; 2A, 1.000; 3A, 0.750; and 1B, 1.950; 2B, 1.300, and 3B, 0.975. The tolerance on major diameter of external threads is equal to 0.09 $\sqrt[3]{p^2}$ for Class 1A and 0.06 $\sqrt[3]{p^2}$ for Classes 2A and 3A. Classes 1A (screws) and 1B (nuts) are intended to cover the manufacture of threaded parts where quick and easy assembly is necessary; Classes 2A and 2B are suitable for parts required to be assembled readily but where smaller tolerances are desired. Classes 3A and 3B have zero allowance and are desired for application where closeness of fit and accuracy of lead and angle of thread are important. The *National Bureau of Standards Circular* **479** gives tables for all dimensions, tolerances, and allowances.

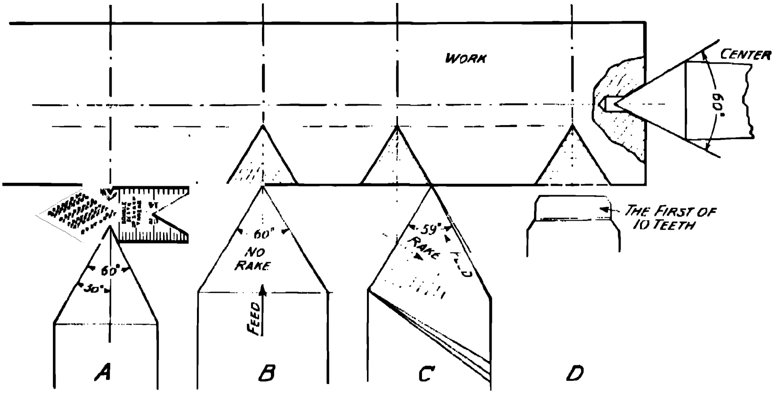


FIG. 78. Methods Used in Cutting Threads on a Lathe with a Single-Point Tool.

At *A*, the Starrett Center gage is shown placed against the edge of the work for locating the V-point threading tool with the left-side cutting edge at 30 deg from a radial line. The tool is shown at *B* ready to take successive cuts in the work, indicated by dashed lines, by being fed radially inward several thousandths of an inch, using the screw of the compound rest, at each pass. The tool at *B*, in order to maintain the 60-deg included angle, is ground flat on top, that is, has no rake. When cutting ductile metals, a cutting tool with a rake angle back of the cutting edge, as illustrated at *C*, may be used to advantage. This tool, having an included angle slightly less than 60 deg, is fed inward at each pass by the lead screw of the compound rest, the latter set at a 30-deg angle from the radial line. A thread being cut by the Rivett thread tool cutter is shown at *D*. This cutter is circular, having 10 teeth. Tooth No. 1, as illustrated, is long and narrow and takes the first cut. Tooth No. 2 extends slightly deeper into the work, etc. Tooth No. 10 finishes the thread to depth. Each tooth is brought successively into use at each pass.

Methods of Forming Threads

Threads may be formed on the inside or outside of a cylinder or cone in several different ways, as follows:

1. With a single-point threading tool, Figs. V-10 and V-12.
2. With a thread chaser, Fig. V-13.
3. With a tap, Fig. 28.
4. With a die, Fig. 25.

5. By thread milling (single or multiple cutter), Figs. VIII-16 and VIII-17.
6. By thread rolling, Fig. 31.
7. By grinding.

Those on the outside surface may be formed by using a **single-point** (or thread chaser) tool, Fig. 78. The tool is fed by means of the lead screw a lateral distance equal to the lead of the screw thread for each revolution of the work. The tool is fed into the work a few thousandths of an inch for each cut. It is withdrawn at the end of each cut to eliminate interference between the tool and work while being returned to the starting point. The work may be reversed as the tool is withdrawn and the tool carriage returned to the starting point by means of the half nut engaged with the lead screw, or the half nut may be disengaged from the lead screw at the end of the cut and the carriage returned by hand to the starting point where the half nut is again engaged after the tool is fed in to proper depth. When cutting internal threads, the tool No. 9 in Fig. V-6, or the one at the right in Fig. V-10 is used.

A **chaser** or multiple pointed tool is shown in Fig. V-13. One, two, or three teeth on the feed side are chamfered so as to distribute the chips over several teeth. In this way complete threads may be cut in one or sometimes two passes of the chaser.

Taps

A **tap,** Fig. 79, as used in forming internal threads, consists of a series of radially placed chasers mounted externally on a cylindrical body. Holes which are to receive studs or screws are usually threaded by the use of taps. The hole is first drilled slightly larger than the root diameter of the thread by using a tap drill, so called because it is followed by a tap. The hole is then threaded by screwing the tap into it. If the tap drill is too small, an excessive amount of power will be required for tapping, resulting in tap breakages and poorly fitting threads. On the other hand, if the tap drill is too large, the threads will not have sufficient depth for strength.

Types of taps: Taps are made in a wide variety of sizes and shapes and for a number of specific purposes (see ASA B5.4, 1948). They may be hand or machine operated, and solid or adjustable. They are designated as serial hand taps, combination, interrupted thread, and collapsible. They may have two or more straight or helical flutes. For use, there are the tapper taps, the nut taps with straight or bent shank, machine-screw taps, pulley, taper and straight pipe taps, staybolt, stove-bolt taps, etc. Tap nomenclature is shown in Fig. 79.

Tap materials: Taps usually are made either of carbon tool steel or high speed steel. High speed steel taps give from four to ten times the production of carbon taps. Carbon taps, however, represent a smaller investment and are satisfactory when used only occasionally, as in the toolroom or job shop, or on soft metals.

Taps for abrasive materials should be very hard, and those for steel or deep holes should be tough.

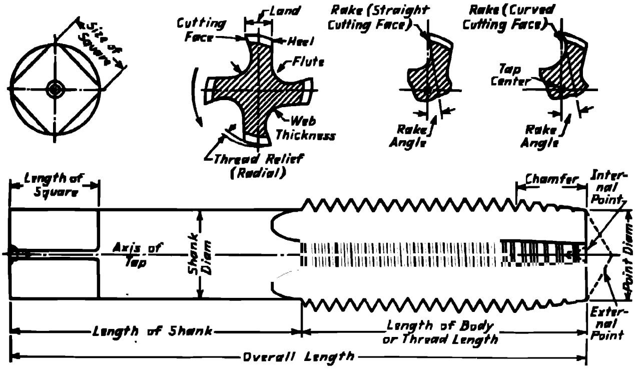


FIG. 79. A Hand Tap with Nomenclature (ASA B5.4, 1948).

Relief: Tap threads may be formed with no radial **relief** or peripheral clearance, i.e., the outer surface back of the cutting edge is circular, or they may be backed-off or formed eccentric. The concentric thread is generally used on small hand taps up to ½ in. diam. or even up to 1 in. diam., unless there is a tendency for the tap land to drag. A relieved tap of nominal diameter will cut slightly larger when new than the concentric tap, but there will be a reduction in diameter when the front cutting faces are reground. About 75 per cent of the taps used are not relieved. Pipe taps are relieved about four times as much as standard. They are ground on the face and on the chamfered end of the tap in order to maintain size. The chamfered end of all taps must, however, have relief back of the cutting edge.

It is good practice to have longitudinal or **back-taper relief**. This makes the pitch diameter of the tap smaller at the shank end than at the point.

Cut and ground threads: Tap threads are finished by **cutting** when soft or **grinding** to size after hardening to produce a better finish and to eliminate decarburized surfaces and distortions set up in heat treating. Taps with ground threads usually are of high speed steel which may be quenched from 2,350° F rather than 2,250° F required for fine-point tools. Ground taps give greater accuracy of size, lead and thread form, greater tap life, higher tapping speeds, fewer broken taps, and greater interchangeability of threaded holes than the cut taps.

Hand or power drive: When tapping is done on a small scale, the tap is commonly turned by hand with an end wrench or tap holder; but when considerable tapping must be done or where excessive power is required, it is better to rotate the tap by power.

Hand taps: Hand taps, Fig. 79, have short square-end shanks, and are used both for hand and machine tapping.

Each size of hand tap is usually made in three degrees of taper or number of **threads chamfered,** such as the taper, plug, and bottoming. The **taper** tap has 7–10 chamfered threads. It is used for tapping through holes where the length of the hole does not exceed one and one-half times the diameter. In long holes, the taper tap has too much cutting edge in operation at one time, which requires excessive torque and often results in tap breakage. The **plug** tap has a 3–5-thread chamfer. This is the most generally used type of tap, particularly in machine tapping. The hole should be drilled deep enough to prevent the tap from bottoming. Lack of this precaution results in many broken taps. The friction slip chuck has been developed to overcome this cause of breakage. The **bottoming** tap has a 1-thread chamfer. It is rarely used, except to follow the taper tap for producing threads to the bottom of a blind hole. The short chamfer tap, taking heavier chips, has a tendency to cut oversize; the long chamfer tap cuts closer to size.

When **tapping by hand,** care must be taken when starting the tap to see that it stands perpendicular to the surface. A tap wrench having double-end handles is used. The leading end of the taper tap is small enough to enter a short distance into the opening to be threaded before starting to cut. This helps to align the tap axis with that of the hole.

In **machine tapping,** the **alignment** of the tap with the hole to be tapped is important. When alignment is not assured, a floating holder should be used to permit the tap to follow the hole without breaking. A hand tap with the "**spiral**" **point** has the flute deepened at the point to give hook and negative helix to the chamfered teeth. This point permits shallow flutes, giving a strong tap. The chips are forced ahead of the tap so they cannot clog in the flutes. These taps are used principally on tough steel, fiber, or hard rubber, but also are very good for tapping long through-holes.

Hand taps may be furnished with two, three or four **flutes.** The smaller-size taps usually have the smaller number of flutes. The number of flutes recommended for ground-thread high speed steel taps

TABLE 13. GENERAL RECOMMENDATIONS REGARDING THE NUMBER OF FLUTES FOR TAPS OF DIFFERENT SIZES WHEN TAPPING DIFFERENT METALS*

Size	Cast Iron	Steel	Aluminum
¼	2 or 4	2	2
5⁄16	2 or 4	2 or 3	2
⅜	3 or 4	3 or 4	3
7⁄16	3 or 4	3 or 4	3
½	4	3 or 4	3
⅝	4	4	4

* Courtesy John Bath and Company.

in different metals is indicated in Table 13. Very few jobs require two- or three-flute taps above ½ in. diam. The **four-straight-flute tap** is best for hand tapping or for machining work in cast iron or material which crumbles rather than cuts into curly chips. The **three-flute** plug taps have larger flutes or chip spaces. This makes possible greater rake angles and still provides strength for use in machine tapping steel and other metals which have a stringy chip. The **two-flute** plug taps are made in small sizes for machine tapping tough material. These taps often succeed where three- and four-flute taps break. A **one-flute** tap is sometimes used for tapping copper.

The flutes may be milled **straight** or **helical.** In some taps, the helix of the flute is at right angles to the helix of the thread. This produces a correct thread form in the hole and gives both angular sides of the thread the same smooth finish. On difficult tapping jobs, the **serial** taps, consisting of two undersize roughing taps and a size finishing tap, have been found practical. Serial taps are marked with rings around the shank near the square, one ring indicating the first rougher with a long chamfer, two rings the second rougher with a short chamfer, and three rings the finisher.

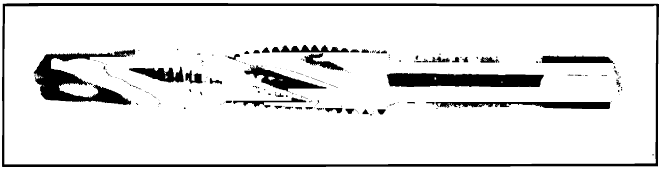
The usual practice to avoid tap breakage is to provide the small taps up to and including ⅜ in. diam. with shanks the full **diameter** of the thread, Fig. 83. Taps 7⁄16 in. diam. and larger are furnished with shanks below the root diameter of the thread. Hand taps are made in a wide variety of **sizes** and **types of threads.**

The **tapper tap,** Fig. 28, has a long shank and long tapered thread. It is used for tapping nuts in quantities. These taps are made in standard over-all lengths of 12 and 15 in. for all sizes from ¼ to 1 in. diam. with any standard type of shank, such as the plain round, the flattened, the square, and other types to fit various machines.

Nut taps are quite similar to the tapper taps in general appearance. They have shanks shorter than the tapper tap and longer than hand taps. The shank is provided with a square tang, similar to that used on hand taps. The nut tap is used for small-quantity production work on bolt cutters, drill presses, etc., for tapping through holes which are not more than $1\frac{1}{2}$ diameters long, and where accuracy and ability to cut a full clean thread are essential.

Pulley taps are quite similar to the plug hand tap having an extra-long full-size shank. They are used for tapping set-screw and oil-cup holes in pulley hubs. The full-sized shank acts as a guide through a hole in the rim of the pulley.

Taps for cutting **Acme** threads are made resembling the usual hand tap. Acme threads require the removal of a great deal of metal so that usually progressive taps are required. Acme taps may be furnished in the single-pass long-taper type, or in sets of two, three, four, or even five progressive-cut taps.



Courtesy Mohawk Tool Co.

FIG. 80. The Mohawk Subland Drill Tap for Use on Through-Holes Such as Plates and Flanges.

The drill size, determined by independent ribs, is approximately equal to the minor diameter of the thread. The tap is formed on a separate set of ribs so that a hole may be drilled and tapped in one pass of the spindle. The drill and tap may be sharpened independently.

The **bent-shank tapper tap** is used in high-production tapping, Fig. 29. These taps are furnished with three flutes up to $\frac{3}{4}$ in. diam.

A **pipe tap** is tapered. As the tap is fed into the pipe, cutting occurs along the whole length of the flute until the proper depth is reached. A straight pipe tap is made for tapping holes for grease-cup fittings, oil-pressure lines, etc. **Interrupted-thread taps,** in which each alternate cutting point along the rib is removed, are furnished on any type of tap for tapping tough metals, such as steel tubing, drawn cups, copper, and brass, or any metal that has a tendency to produce torn threads resulting from pinching between two adjacent teeth of the tap. For best results, interrupted-thread taps having a thread with single lead should have an odd number of flutes to follow correctly.

A **combination drill tap** for drilling and threading the hole in one pass is shown in Fig. 80.

Collapsible taps and self-opening die heads are provided where it is not desirable to change the direction of rotation of the tool or work to withdraw the tap or die after finish-cutting the thread. Such a nonrotating collapsible tap with four radially placed chasers is shown in Fig. 81. A self-opening rotating die head is shown in Fig. 25.

Threading Dies

A **die**, Fig. 82, as used for cutting external threads, consists of a series of internal radially mounted chasers. The teeth of small chasers are cut on a helix to draw them onto the work after being started. The teeth on large chasers are usually cut straight, Fig. 25, a lead screw being used to advance the die on the work. The leading ends of the chaser threads are chamfered to form a throat into which the work is fed. This throat not only guides the work into the die or the die onto the work, but also serves to distribute the cutting over a greater number of teeth.

FIG. 81. The Murchey Machine and Tool Co. Lever Handle-Type Nonrotating Collapsible Machine Tap.

This tap is used on machines having stationary tool spindles, such as turret lathes and screw machines. Where the spindle revolves, as on tapping machines and drill presses, a sliding collar type of tap is used, such as employed on the die shown in Fig. 25. The chasers collapse automatically, after cutting any desired length of thread within their limit, by means of a tripping ring set to come in contact with the face of the work after the required length of thread is cut. The tap is then ready to be withdrawn, after which the chasers are expanded by means of the lever handle. They are made in sizes from 1¼ in. to 12 in. diam.

Dies used for cutting external threads are made for a wide variety of purposes and in a number of types, as follows:

1. The solid die.
2. The adjustable die, Fig. 82.
3. The spring adjustable die, Fig. 84.
4. The self-opening die head, Fig. 85.

There are a number of **types of solid dies**, such as the hexagonal rethreading die, the square-pipe die, and the round screw-thread die.

The **adjustable** dies, Fig. 82, are so constructed that the die may be set to a master cut slightly oversize or undersize by expanding or contracting it. These dies are held in diestocks when being used in hand tapping, as shown in Fig. 23, or in a bitbrace shank holder. A small set of hand taps and adjustable dies with wrench and stock is shown in Fig. 83.

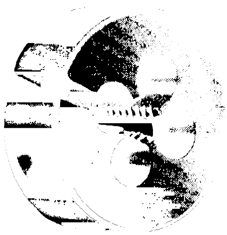
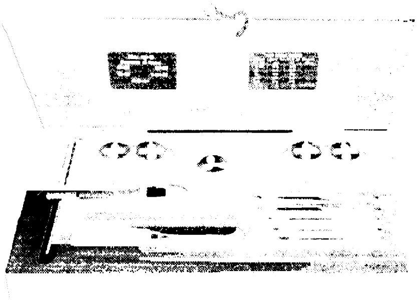


FIG. 82. Adjustable Round Split Die with Adjusting Screw; Made in Fractional and Machine-Screw Sizes.



Courtesy Greenfield Tap and Die Corp.

FIG. 83. "O.K." Jr. Round Die Screw Plate for Hand Use.

One plug tap and one ⅞-in.-outside-diam. die is furnished for cutting National coarse threads. The stock or die wrench clamps the die in place by the single screw. The T-handle tap wrench has a four-jaw chuck for gripping the square ends of the taps.

Spring screw-threading dies for machine use are adjustable by having a collar threaded over the tapered end of the die, or by having clamped collars, Fig. 84.

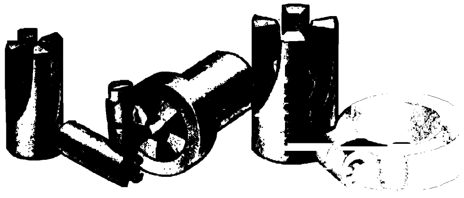


FIG. 84. Spring Screw-Threading Dies for Machine Use.

The clamp collars provide easy adjustment of size. The dies are made with 2½ to 3 threads chamfer, and produce a very good form of thread, lead, and finish. The cutting edges are regularly made slightly ahead of the center to give a rake.

Die heads are bodies in which chasers are mounted radially, Fig. 85, or tangentially, Fig. 25. The chasers, of cutting-tool steel, are adjustable and replaceable. Many die heads are **self-opening,** i.e., they are so constructed that the chasers are in the correct threading position when the die is fed onto the work. At a predetermined position within a short distance from the end of the thread to be cut, the turret or toolholder is stopped while the front portion of the head continues to advance. After a short advance, a lock is disengaged which releases the chasers and allows them to expand radially away from the work so that the die head may be withdrawn over the work without damage to the cut threads. The chasers of the die head, as well as those of the collapsible tap, are then restored to their cutting position by means of the handle, just before the start of the next cut.

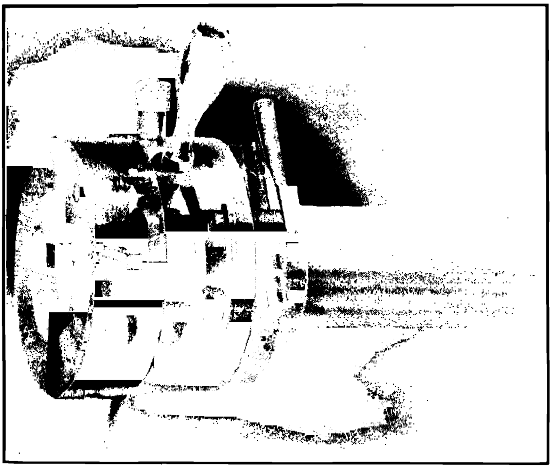


Fig. 85. A Phantom View of the Geometric Tool Co. Self-Opening Die Head Containing Four Radial Chasers.

This is a nonrotating head universally used for producing screw threads on hand screw machines. Fine adjustments of the thread size are permitted.

Die features: There are a number of important features to be considered in the application of threading dies, such as rake angle, lead or chamfer, chip space, relief angle, number of chasers, and cutting fluid used.

The teeth of the chasers may be hobbed, cut straight, or turned, Fig. 86. Those cut straight may be milled, and the straight and cylindrical ones may be ground.

The relief is the space between the threads of the chasers and those of the work. Teeth cut straight are cut on a bevel to provide proper relief. Hobbed cutters are cut by a hob cutter of a diameter larger than that of the work to be threaded so that, when the chaser is brought to its proper position for threading, a sufficient clearance will be provided between the cut threads of the chaser and those of the work. Some die heads locate the cutting edge of the chaser on a radial line;

others locate the center line of the chaser on the radial line so the cutting edge is offset. The cutter must be ground to provide the correct **rake and relief angles**, Fig. 86. For most work on cast iron, brass, and bronze, malleable iron, hard rubber, plastics, and hard steel, 0–5 deg rake is sufficient; for steel in general 8 deg, for magnesium, Monel, and stainless steel 12 deg; and for aluminum 20–40 deg. The National Tube Co. recommends a 15–20-deg rake angle when threading Bessemer steel pipe, and at least 25 deg when cutting open-hearth steel pipe. The face should be curved for all soft steels and ductile metals back of a rake of 5–10 deg so as to curl the chips.

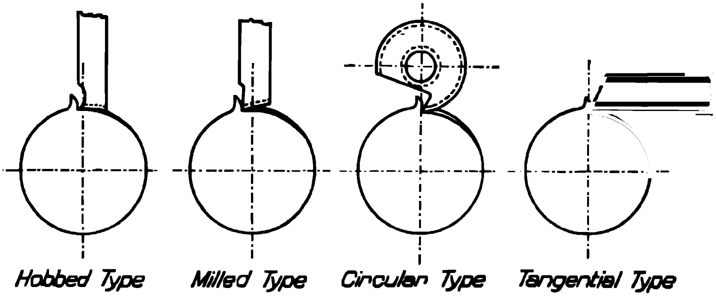


Fig. 86. External Thread Cutters.

The cast phenolics are tapped and threaded with standard tools. However, the ground high speed steel taps with large polished flutes, with 3 instead of 4 flutes or 2 instead of 3 flutes, are preferable. Tapping speeds are usually from 40 to 60 fpm and water serves as a good cutting fluid, as it keeps the material brittle and prevents it from sticking in the flutes. As taps become worn because of the abrasive action of the plastics, they will cut undersize. Thread cutting is generally accomplished with tools similar to those used on brass.

The **chip space** should be sufficient to permit the coiled chips of ductile metals to roll and flow from the die head, rather than become cramped and clogged. If sufficient chip space is not allowed, the chips will pack rapidly in front of the chaser, causing rough, torn threads.

Cutting fluids of kerosene or paraffin oil plus 5 per cent lard oil or oleic acid are good for threading aluminum and its alloys. Emulsions or paraffin are used on wrought brass and bronze, copper, and malleable iron, and sulphurized oils generally give best results in threading all ductile steels, iron pipe, wrought iron, and Monel. It is important to lubricate the chips in the flutes.

The **lead** is the angle of chamfer which is machined or ground on the first few threads of each chaser to enable the die to start on the work and to distribute the cutting over a number of teeth. The lead, as with the taper or chamfer in taps, may be machined on before hardening, or, as is more frequent, it may be ground on after the chasers are hardened and tempered. About three threads are chamfered. As most of the cutting is done by the chamfered teeth, they should have a slightly greater relief angle than the rest of the threads on the chaser. The outside diameter of the throat should be slightly greater than that of the pipe or bar to be threaded.

The **number of chasers** of a die must be determined by the amount of metal to be removed. For pipe threading dies, the National Tube Co. recommends that dies on power machines up to 1¼-in. size should have at least four chasers; 1½–4 in. should have at least six chasers; 4½–8 in. should have eight chasers; and 9–12 in. should have at least twelve chasers. With an insufficient number of chasers, the dies will chatter and cut a rough thread.

Threading speeds: It is difficult to give definite information as to threading speeds, in view of the unlimited variety of materials of different cutting qualities to be tapped with carbon-tool-steel and high speed steel taps. Taps which operate perfectly in one place will give trouble in another place where conditions seem to be identical. This indicates that very slight changes in the metal cut, the taps, the speed of operation, the cutting fluids, or the equipment used, materially complicate the situation.

As a general rule, threading with carbon-steel taps and dies is done at speeds of 10, 15, or 20 fpm. The slowest speeds are used for hardest materials and small taps; the larger speeds are used for the softer materials and larger taps. Tapping or threading brass may be done at speeds several times greater than those for low-carbon steel. When high speed steel taps and dies are used instead of carbon steel, the speeds may be doubled or even trebled. Ground high speed steel taps often are operated at drilling speeds.

Torque and power in threading: The **torque** in threading is practically independent of speed. For cutting American Standard NC threads in SAE 1112 screwstock with self-opening die heads with chasers having a 20-deg chamfer covering two threads, and 7-deg rake, typical values in pound-feet are 2 for ¼ in. by 20 threads, 3.25 for 5⁄16–18, 4.375 for ⅜–16, 8.7 for ½–13, 14.5 for ⅝–11, and 21.5 for ¾–10. These values of torque plotted over diameter on log-log paper give a straight line $T_{NC} = 40d^{2.14}$. Torque for the NF threads are 2 lb-ft for ⅜–24, 4.5 for ½–20, 6.2 for ⅝–18, and 9.5 for ¾–16, giving the equation $T_{NF} = 17.3d^{2.14}$. The net **horsepower** at the tap due to torque equals $\frac{2\pi TN}{33,000}$, in which N is the speed in revolutions per minute.

The torque or power for threading other metals may be obtained by multiplying those for SAE 1112 steel by factors as follows: aluminum, 0.45; brass, 0.63; SAE 1020,* 1.10; SAE 3135* and 2320,* 1.21; SAE 1045* and 1335,* 1.27; SAE 3140,* 1.37; SAE 2330 heat treated, 1.47; SAE 1045 heat treated, 1.68 (*Machinery*, November, 1932). For tapping cast iron with NC taps a value of 2 and for NF a value of 0.75 of that required to tap SAE 1112 steel may be used.

The Hoefer Manufacturing Co. found that Briggs pipe taps in cast iron give a formula for torque in pound-feet of $T = 100d^{1.38}$. Typical values are 6 lb-ft for ⅛-in.-diam. tap; 17 lb-ft for ¼ in.; 26 lb-ft for ⅜ in.; 46 lb-ft for ½ in.; 60 lb-ft for ¾ in.; and 100 lb-ft for 1 in.

Machines for Grinding Drills, Boring Tools, Reamers, and Threading Tools

There is a wide variety of types and sizes of machines on the market for grinding cutting tools used for drilling, boring, reaming, and threading. The machine in Fig. 87 is equipped with a wheel at one end of the motor shaft, and attachment for dry grinding (pointing) drills and a straight wheel for general hand grinding on the other end. The arm carrying the V's, in which the drill rests, is inclined to provide the standard point angle of 118 deg. The Sellers No. 6G drill grinder, Fig. 88, points twist and flat drills from 5/16 in. to 3 in. diam. at any point angle from 60 to 130 deg. The drill is supported on an adjustable shank center and two jaws bearing on the margins near the point. Grinding may be done under a copious supply of coolant. The Sellers No. 1G drill grinder, Fig. 89, is for small drills (from 0.028 in. diam. to ½ in.).

The Oliver drill pointer grinds a relief back of the cutting edge which is considerably greater at the end of the chisel point than at the periphery. Strong claims are made for this type of drill-point grinding. Special grinders also are provided for point thinning, as required for drills after being sharpened several times when the web thickness is increased. A straight wheel rounded on the periphery grinds in the flute at an angle of about 15 deg from the axis of the drill. Care must be taken to keep the new chisel edge on center, as shown in Fig. 45.

* = annealed.

Boring tools, reamers, and taps are sharpened usually on universal tool and cutter grinders, such as those used in grinding milling cutters. Tools of this type are best supported on centers or in collets while being ground.

The grinding machine for **reconditioning taps** is shown in Fig. 90. The illustration at the top shows the head for **chamfering.** The tap held in a collet *9* by its shank is brought against the face of a straight wheel and rotated through a small arc according to the setting for the number of flutes and amount of chamfer. Collets of most sizes up to 1¼ in. diam. are standard equipment. Operating lever *1* is brought forward till the stop on the drum holding the collet is stopped by pin *6* located in a hole corresponding to the number of flutes of the tap. The drum *5* is adjusted in or out and held by the plunger *3* in a position corresponding to the number of flutes. The tap is rotated in the collet until the cutting edge of one land is in line with the horizontal center line of the wheel *12* and located accurately by the finger *18* supported from a hole in the face of the head; then the collet is tightened with knob *4*. The graduation *7* is set to give eccentric relief for right- or left-hand taps. The head is adjusted in the sliding base arm *17* which

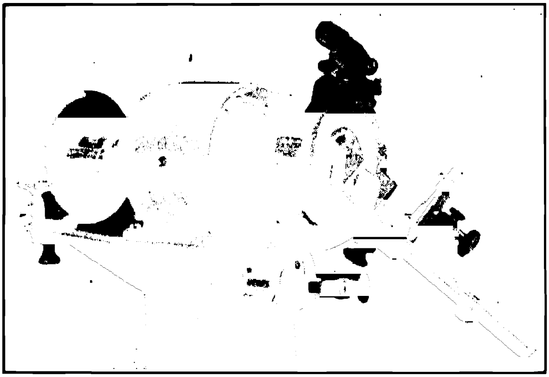
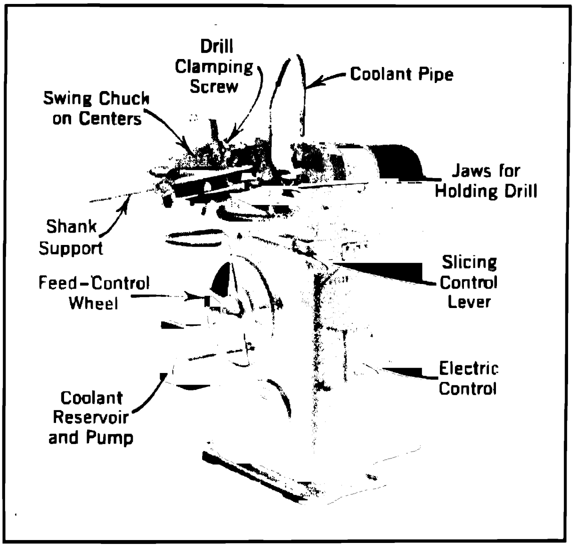


FIG. 87. The Covel Manufacturing Co. "New Yankee" Motorized Grinder.

The cup wheel, A46-K5VBE, on the right end of the spindle is arranged for pointing drills. The drill is rested in the V's with the shank supported on the adjustable center. The fluted edge of the drill is forced clockwise against a small plate at the left end of the large V. In this position, the whole arm supporting the drill is oscillated about an inclined axis just below the wheel. While the drill is being oscillated against the abrasive wheel grinding one lip, it is fed slowly forward into the wheel by means of the knurled handwheel on the shank center. After one lip is lightly ground, the drill is rotated 180 deg, and the second lip is ground. A wheel dresser is shown attached to the top of the wheel guard. This dresser may be swung into position and forced against the wheel to true it up and sharpen it. The whole arm and inclined axis are adjustable to and from the wheel on the horizontal shaft just below the motor. A straight abrasive wheel is mounted on the left end of the motor shaft for general tool grinding by hand. An adjustable T rest is provided.

is swung to the desired angle of chamfer indicated on graduation *15*. After removing the locating finger *18*, truing the wheel with the diamond *10* supported on pin *11*, the wheel is moved against the tap by wheel *14*. To index, the plunger in the sleeve *5* is withdrawn by depressing the trigger *2* and turning to the next hole.

For **flute grinding** as shown at the bottom, Fig. 90, the tap is located in the collet and clamped by the nut *1*. Knob *11* provides cross traverse, and wheel *14* tilts the table to the proper incline, which is clamped by the nut *13*. The wheel is hand dressed by a honing stick to the contour of flute desired. The tap is located under the wheel in a tangential position and traversed by the crank *12*. The index disk *3* has notches for the trigger *4* to correspond with the number of flutes in the tap. After grinding one flute, the tap is indexed by releasing the trigger, turning the spindle by hand until the trigger engages in the next notch.

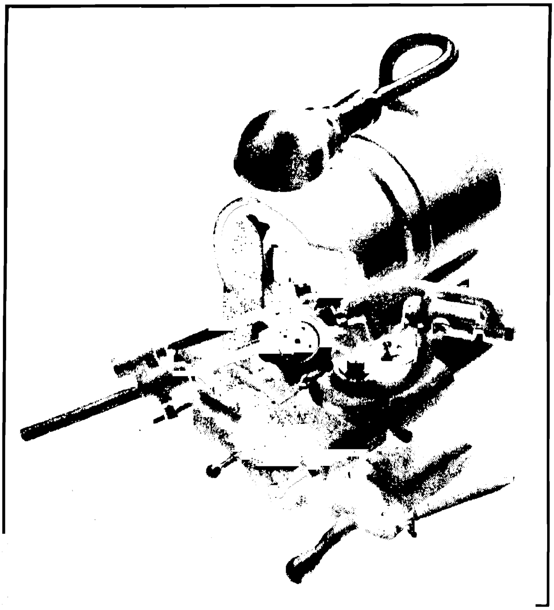


Courtesy Consolidated Machine Tool Corp.

FIG. 88. The Sellers 6G Drill Grinder for Drills 5⁄16 in. to 3 in. diam.

This is a wet grinder. Rough grinding is accomplished by taking a succession of heavy cuts holding the chuck stationary and passing the wheel across a narrow portion of the lip, turning the chuck slightly for each successive cut until the whole flank is reground. Then, by oscillating the chuck and passing the wheel lightly over the cutting edge, a smooth flank is obtained. The drill point can be adjusted from 60 to 160 deg.

For grinding the spiral (helical) point the tap is tilted to the desired angle on scale *5*. The stop *9* is set so the tap can be fed to the required distance in both flute and point grinding.



Courtesy Consolidated Machine Tool Corp.

FIG. 89. Sellers No. 1G Bench-Type Drill Grinder.

Drills from 0.028 in. (No. 70) to ½ in. diam. having drill point angles from 65 to 160 deg with any desired relief angle can be ground. The drill is inserted with the tang in the V recess, and the body supported in the jaws on the margin with the point of the drill extending beyond the chuck jaws about 1½ the drill diameter. A ¼ turn of the chuck handwheel clamps the drill. The drill point is next positioned on the face of the wheel by means of the lever at the bottom. As the drill is oscillated on its supporting frame, it is gradually fed against the wheel by the two-handled graduated dial. The drill is then indexed 180 deg for grinding the second cutting edge. A cup wheel of a general type A46KV is used.

The throat of thread chasers for die heads is ground by hand or on machines especially designed for the purpose. In grinding reamers and boring tools, the grinders must be in good condition. Wheels similar to those outlined in connection with grinding milling cutters have been found most satisfactory.

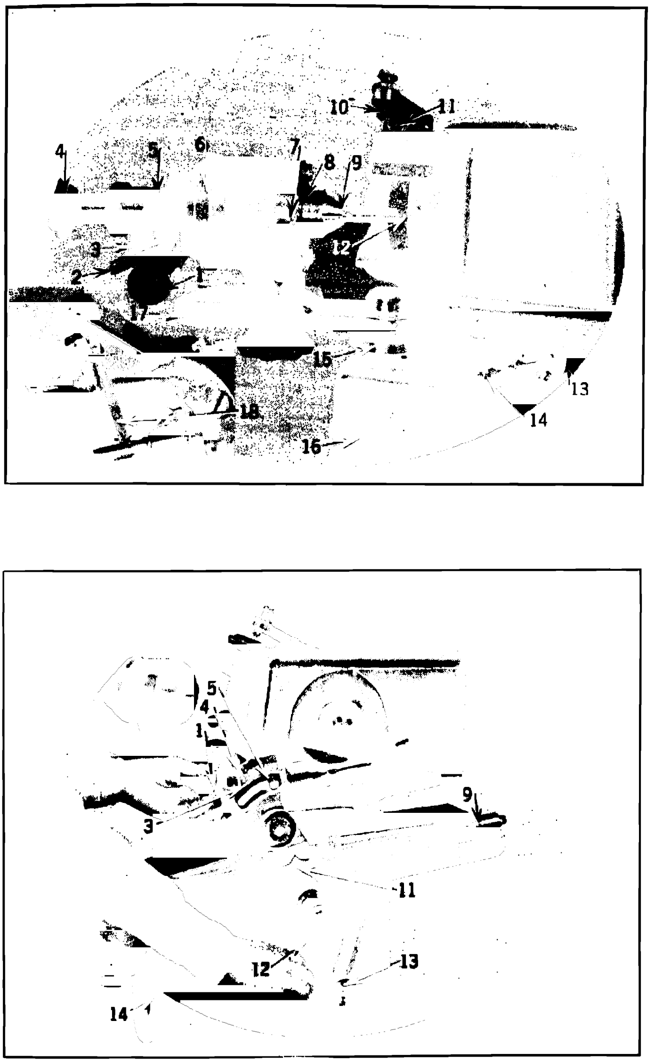
QUESTIONS

1. Explain the advantage of a round-column type of drill press over the box type as it affects the maximum height of work that may be drilled.

2. Explain the advantage of the adjustable table on a drill press.

3. Explain the advantage of the sliding head on a drill press.

4. What is meant by counterbalancing the spindle?



Courtesy Detroit Tap and Tool Co.

FIG. 90. A Tap Reconditioner for Grinding Chamfers, Flutes, and Spiral Points.

This is a pedestal-type machine with a cabinet in the base with two wheels and heads. The head at the top is for grinding chamfers, while that at the bottom is for grinding the flutes for rake and the chip driver type of spiral point.

5. Explain the difference between a drill-press spindle and the quill.

6. Explain how a spindle is fed by hand.

7. Explain the purpose of the gear rack on the quill and the worm and worm wheel in the power-feed drive.

8. What characterizes a general-purpose drilling machine; a production-type drilling machine; and a single-purpose drilling machine?

9. What is the advantage of a multiple-cluster-type drilling machine over the single-spindle machine equipped with a fixed-center multiple-drill head?

10. Explain how a ½-in.-diam. drill with a No. 1 Morse taper shank may be fitted to a spindle of a drill press having a No. 4 Morse taper hole.

11. What is the difference between a sleeve and a socket?

12. What is meant by point thinning?

13. What are the names and angles of a two-fluted twist-drill point?

14. Explain the difference in construction and use between a fluted and rose chucking reamer.

15. What is the difference between a counterboring tool and an end mill?

16. What are the purposes of right- and left-hand helical and straight flutes on fluted reamers?

17. What is a drift, and how is it used?

18. What is meant by a self-opening die head?

19. What is meant by the lead or throat of a die, and what is its purpose?

20. When high speed steel tools are used in cutting malleable cast iron, what would be the general relation between the cutting speeds in feet per minute used for a drill, counterboring tool, reamer, and tap?

21. Explain and show by formula how the total net power at the point of a drill is determined.

22. Explain the difference between the net power developed at the drill point and the gross power developed by the motor.

23. What is meant by a tapping attachment? Explain how one should work.

24. In preparing the holes in a medium-hard cast-iron cylinder block of an automobile engine in which studs are fitted, three operations are required, i.e., drilling, reaming, and tapping. The stud used is a $\frac{7}{16}$-in.-diam. American Standard fine thread. A $\frac{3}{8}$-in.-diam. tap drill is followed by a $\frac{25}{64}$-in.-diam. rose chucking reamer. Indicate clearly in each part below the speeds and feeds on which your computations are based.

(*a*) Determine the actual cutting time for drilling a full diameter to a depth of 1¼ in. if high speed steel twist drills are used.

(*b*) Determine the time to ream the hole to a depth of 1⅛ in.

(*c*) Determine the time for tapping, if a high speed steel tap is used having five incomplete threads and producing full-depth threads in the hole to a depth of ⅞ in.

25. A plate of low-carbon steel is 2 in. thick. Determine the cutting speed in feet per minute and revolutions per minute, and the feed in inches per revolution for the following high speed steel tools, each 1 in. diam.

(*a*) A two-fluted twist drill originating the hole.

(*b*) A three-fluted core drill enlarging the hole from ⅞ to 1 in. diam.

(*c*) A rose chucking reamer removing 0.020 in. on the diameter.

(*d*) A fluted chucking reamer removing 0.006 in. on the diameter.

(*e*) An American Standard coarse series tap.

(*f*) A two-fluted twist drill of carbon tool steel.

26. Using information given in Table 5 and on page 335, determine the following:

(*a*) The torque horsepower at the drill point for a 1-in.-diam. drill operating at 228 rpm with a feed of 0.013 in. when cutting SAE 6150 steel with the drills described, using an emulsion of 1 part soluble oil to 16 parts water.

(*b*) The horsepower of the thrust at the drill point, using formula values.

(*c*) The total power developed at the drill point.

(*d*) If the efficiency of the motor and machine under the above load is 65 per cent, what power in horsepower and kilowatts is developed by the motor?

27. Make calculations similar to the problem above when cutting cast iron with a 1-in.-diam. drill, as indicated in Table 5.

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CHAPTER XI

TURRET LATHES, SCREW MACHINES, AND HAND-CONTROLLED PRODUCTION TURNING MACHINES

DEFINITION

Turret lathes and screw machines are those lathes which are provided with a turret to carry the cutting tools in place of a tailstock for machining either bar stock or chucked work. These machines are built in a wide variety of patterns as well as a wide range of sizes. They are used for work done in small lots or moderate quantities in which the engine lathe with its various appliances is too slow or relies too much on the human element, and where the full automatic turning machines either are too expensive or require too much time to tool up for the limited production.

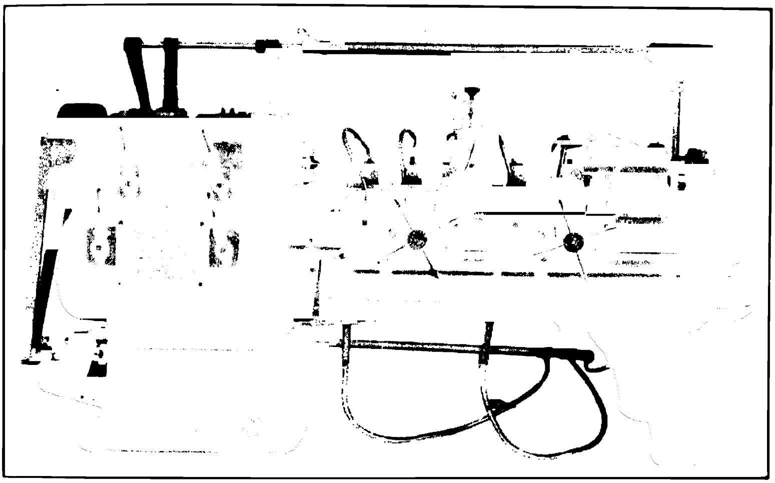
Some hand-controlled production machines have only slides instead of a turret to carry the tools. They may be used for machining chucked work or short bars held on centers.

CLASSIFICATION

Hand-controlled turning and facing machines for small-lot production are classified into two main divisions—those having **turrets** with or without cross slides and those having only **toolslides.** Those having turrets are subdivided into **turret lathes** and **screw machines.** Turret lathes are usually provided with a 2-, 3-, or 4-jaw chuck and are used to machine work held in the chuck. The spindle of the screw machine, on the other hand, is equipped with a collet to hold bar stock from which parts are machined. There are other types of hand-operated small-lot production machines made for specific purposes, such as crankshaft lathes, pulley turning lathes, and carwheel lathes.

TOOLSLIDE LATHES

The toolslide type for small-quantity production is represented by the Lo-swing lathe, Fig. 1. It is for machining bars or shafts held on centers. It is similar to the engine lathe, except that one or more tool carriages or slides are provided, and each slide is capable of carrying a number of cutting tools. Shafts or parts having a number of different diameters may be turned with one pass of the longitudinal toolslide, or a number of different shoulders or faces may be machined with one pass of the transverse toolslide. Provision is made so one toolslide may be used for facing cuts after the others have finished turning, as shown at the right end of the spindle in the second operation in Fig. 2.



Courtesy Seneca Falls Machine Co.

FIG. 1. The Lo-swing Toolslide Lathe for Small- or Medium-Lot Production.

This is a single-pulley drive machine arranged with two carriages. Each carriage supports tools mounted in front of the work. The tool carriages may be fed longitudinally by hand or power, or each toolholder may be fed transversely. When required, tools may be used in a rear carriage mounted on the back of the machine for squaring shoulders, necking, or making formed cuts. One or more roller-back rests are provided to prevent the springing of the work. These machines are built in 4-in. and 8-in. swing capacities.

TURRET LATHES

The turret lathe is a modified form of the engine lathe. The tailstock is replaced by a turret having 4, 5, 6, or 8 sides, Fig. 3, which is capable of carrying one or more tools on each face so that a tool or a set of tools is brought into play for each side or position of the turret. The several sides make it possible to follow one set of tools by another so that a hole may be **successively** drilled, bored, and reamed, and other surfaces may be rough and finish turned, or turned, chamfered, and threaded, i.e., one machining operation may be followed by another or several, all at one chucking. The bed of the sliding ram is clamped onto the ways of the lathe bed in a fixed desired position.

The compound rest of an engine lathe may be replaced by the 4-way tool-post turret, Fig. 4. A rear tool post also is provided for an inverted tool. The 4-way tool post permits four different tools to be used successively on the cross slide for various purposes. The above

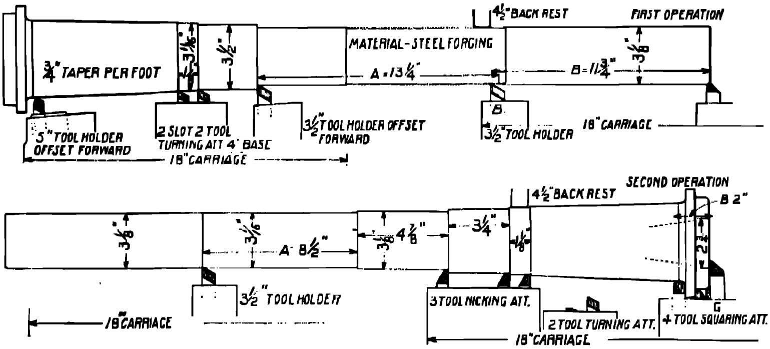
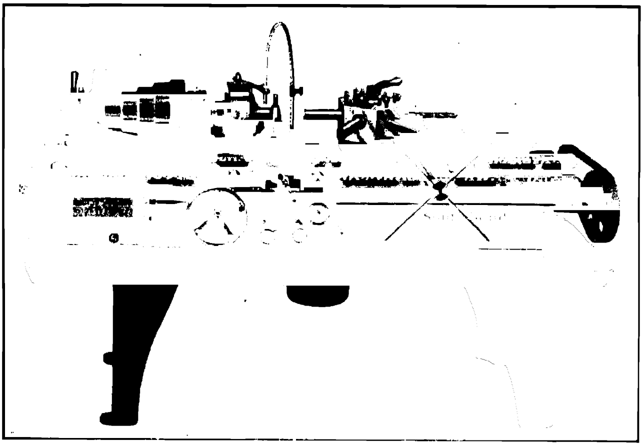


FIG. 2. The First- and Second-Operation Setups on the Lo-swing Lathe Show the Tooling for Finishing Forged-Steel Milling-Machine Spindles, from the Forged to Grinding Sizes, with Tools Shown in Position at End of Cut.



Courtesy The South Bend Lathe Works.

FIG. 3. The South Bend Lathe Equipped for Manufacturing Work.

The standard step-cone pulley, back-geared screw-cutting engine lathe, already provided with an oil and chip pan, cutting-fluid pump, reservoir, and piping, has the tailstock replaced by a turnstile bed turret which changes the toolroom lathe into a hand-production machine for small duplicate parts. The turret head is semiautomatic and will revolve one-sixth of a turn with each hand revolution of the turnstile on the return stroke of the ram. It is fed by power on the cutting stroke from the pulley mounted on the right end of the lead screw. Each face of the turret can be fed forward to any position as determined by the adjustable stop screws shown on the right-hand end of the ram.

and similar attachments are used to convert the engine lathe into a low-production machine.

When continuous small-lot production jobs are anticipated, machines especially constructed with desirable built-in features are used. Machines of this type are the **turret lathe** for machining chucked work, and the **screw machine** for machining parts from bar stock. The **universal** turret lathe is so constructed that it may be set up in a short time for any chucking work, or quickly adapted for bar work.

Courtesy Gisholt Machine Co.

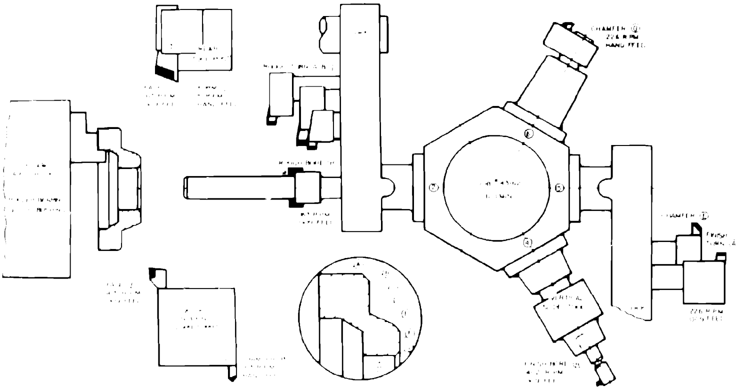
FIG. 4. The Gisholt No. 4 Universal Ram-Type Turret Lathe Set Up with Chucking Tools for Machining a Collet Hood from a Steel Forging Held in the Chuck.

These are typical tools for a semiproduction chucking job. The 12-in. 3-jaw chuck is operated by an air cylinder, and the machine is provided with a speed selector on the head. The tools shown in the setup are illustrated in the following drawing.

A **classification** of construction features of turret lathes follows:

(*a*) Horizontal, Fig. 4, or vertical, Fig. 7.
(*b*) With stationary head, Fig. 6, or cross-sliding head.
(*c*) With geared head, Fig. 6.
(*d*) With cross slide, Fig. 6.
(*e*) With power feed to the turret or without.
(*f*) With cross-sliding turret or without.
(*g*) With ram turret, Fig. 4, or saddle type, Fig. 6.

The Gisholt turret lathe, Fig. 4, is provided with a speed selector. The speeds are selected for the proper sequence of each job by adjusting the number of pointers attached to the handwheel. The cutting speed in feet per minute is set on the dial, and the pointers are set to the diameters of the work. The gears are shifted hydraulically at the proper time to insure the correct cutting speed for each diameter. The feed, stop, and reverse lever directs hydraulic pressure for engaging and disengaging the driving clutches and for applying the spindle brake.



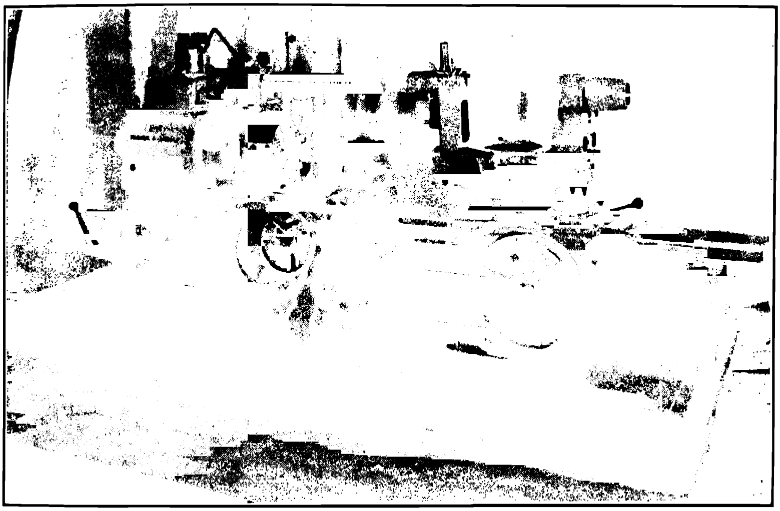
Courtesy Gisholt Machine Co.

Fig. 5. A Line Diagram of the Tooling for the Second Operation on a Collet Hood.

The back of the steel forging of SAE 3140, Brinell 231, has been machined.

The tools and work shown in the setup of Fig. 4 are sketched in Fig. 5, from which the various operations on the part and the tools required to perform them can be identified. The making of such a sketch is the common procedure in setting up such a job.

A heavy-duty **universal turret lathe** is represented by the Warner and Swasey No. 2A saddle-type machine of Fig. 6. This machine carries a 3-jaw universal chuck with a variety of toolholders mounted on the turret. The multiple heads attached to the turret face carry bushings, which engage the pilot bar mounted on the headstock to provide rigidity to the turret and reduce the deflection of the various tools. Long boring bars mounted on the turret may extend through the chuck and engage a bushing fixed in the forward end of the spindle for the same purpose. This universal machine may be adapted for chucking work, as shown, or for bar-stock work. Its chucking capacity is 21½ in. diam. over the bedway covers. It will take bar stock up to 3½ in. in diam. It has the American Standard flanged spindle nose type A, 11 in. size. A 10- or 15-hp motor is provided, depending upon the type of work. It is mounted on the rear of the headstock and drives to the headstock with multiple V belts. Twelve spindle speeds from 17 to 460 rpm are available. These may be preset with a Preselector mounted on the headstock.



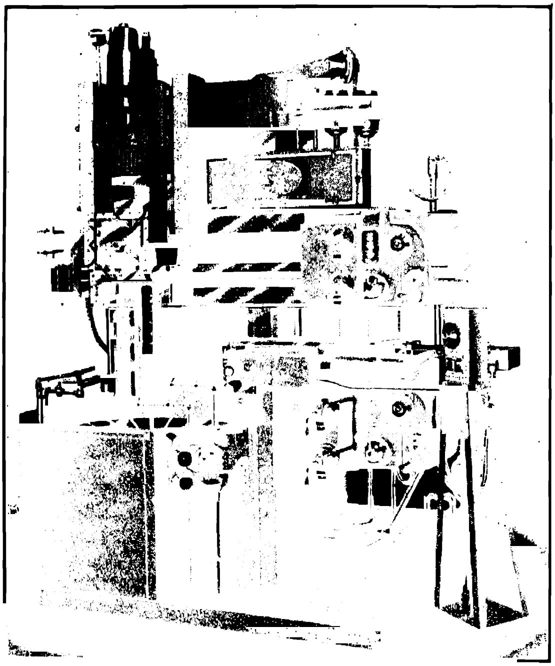
Courtesy Warner and Swasey Co.

FIG. 6. The Warner and Swasey No. 2A Universal Hollow Hexagonal Saddle-Type Turret Lathe Arranged for Chucking Work.

This machine is the latest model. A plain multiple turning head and adjustable single turning head, together with two flanged toolholders, are mounted on the turret. The multiple tool head carries bushings to engage the overarm attached to the headstock to provide rigidity. A speed selector is mounted on the headstock.

The chart shows the recommended speed for each cut, so that the proper spindle rpm is automatically selected by the single lever for each diameter and cutting speed desired. A hydraulic brake is provided in the headstock for stopping the spindle quickly. The headstock is lubricated by a forced spray of filtered oil circulated by a separate pump from an independent cooling reservoir. Multiple disk clutches, hardened alloy steel gears with ground teeth, hardened and ground spline shafts, and antifriction bearings are used throughout. Sixteen longitudinal feeds from 0.004 to 0.149 in. are provided to the turret and carriage. The same number of power feeds of half values are available for the cross slide.

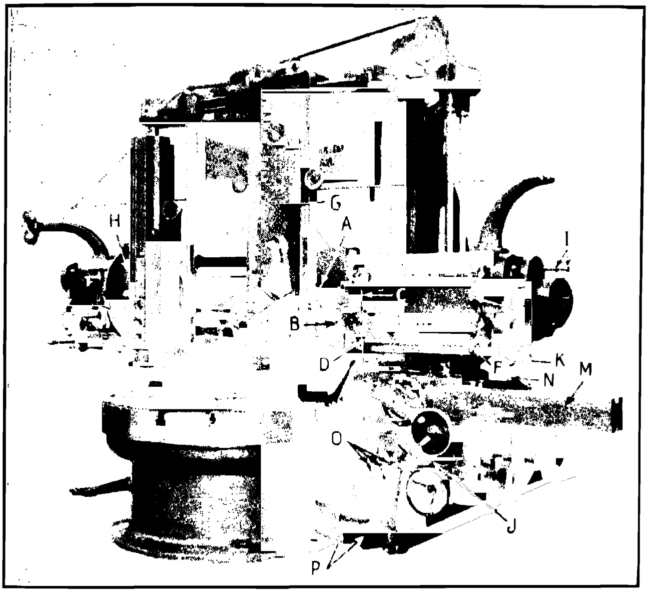
A vertical turret lathe is shown in Fig. 7. This machine has one side head carrying a four-way automatically indexing turret tool post and one four-faced turret mounted on a vertical ram carried on the cross rail. It is made in sizes having table diameters of 30-, 36-, 42-, and 54-in. capacities. The machine is known as the Man-Au-Trol inasmuch as the machine can be set up for a complete semiautomatic cycle, but by moving one lever it is available for manually operated work on any other desired cycle. Each machine has 16 feeds and 20 speeds. A 15-hp motor is used on smaller machines, and a 50-hp motor on larger ones. This machine is particularly adapted to the manufacture of large, complicated work in which the production is large or small, as may be required in experimental or in production work. There are accurately graduated dials for determining the limitations of tool travel in all directions. Vertical and horizontal motions of the main and side heads have 39 stops to control distance and direction. Each machine may be purchased in a high, intermediate,



Courtesy Bullard Co.

FIG. 7. The Bullard Man-Au-Trol Vertical Turret Lathe with One Four-Faced Turret on a Vertical Ram and One Sidehead Carrying a Four-Way Turret Tool Post.

or low speed range, depending upon the type of work anticipated. **Centralized control** is available for both the turret slide and cross slide with all levers and operating handles within convenient reach of the operator from one position. Both driving and feed gears are lubricated continuously and automatically with filtered oil. **Multiple cuts** may be taken with two or more tools in any face of the turret, or **combined cuts** may be made with tools of both turrets working simultaneously to reduce machining time.



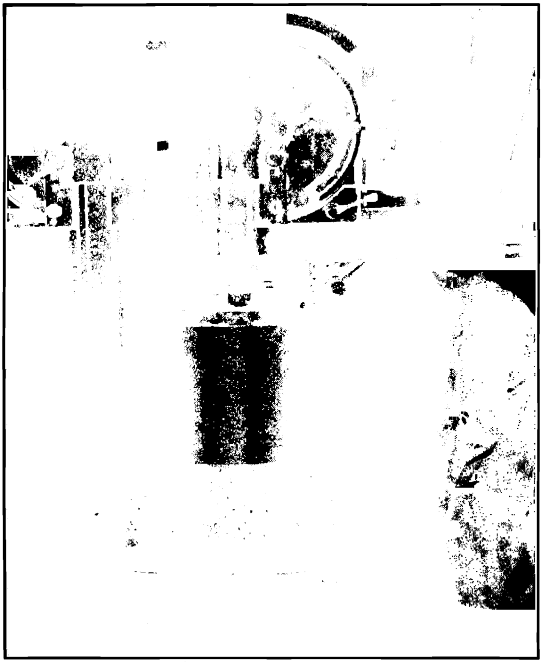
A, ram clamping handle; *B*, saddle clamping handle; *C*, crank for vertical movement of turret slide; *D*, crank for horizontal movement of turret carriage; *E*, directional control handle for vertical movement of right-hand ram; *F*, directional control handle for horizontal movement of right-hand head; *G*, turret slide; *H*, left-hand swivel head; *I*, feed-change levers; *J*, sidehead vertical directional control handle; *K*, handle for rapid traverse or feed for right-hand head; *L*, directional control handle for horizontal slide; *M*, horizontal slide; *N*, sidehead rapid-traverse or feed handle; *O*, table speed-change handles; *P*, start-stop treadle.

Fig. 8. A King 62-in. Vertical Boring Mill.

The machine is driven by a 20- or 25-hp, 900-rpm, constant-speed motor. It is built throughout to stand a 40-hp motor if required. One vertical ram on the rail carries a 5-face turret; a second swiveling vertical ram on the rail carries turning or facing tools; and a third ram mounted on the column at the side carries a 4-way tool-post turret. A 3-hp, 1,750-rpm motor mounted on the bridge is used for the elevating and rapid-traverse mechanism.

Vertical boring and turning mills, Fig. 8, may be furnished with one or two plain swiveling heads on the crossrail and with or without the sidehead. The table consists of a large faceplate with radial T slots, provided with four independently operated reversible jaws. Machines of this type are made to take work up to 40 ft diam.

The King 72-in.-diam. table machine has 16 speed changes ranging in geometrical progression from 1.7 to 55.4 rpm of the table. A speed of 150 rpm can be arranged for high-speed cutting as with sintered-carbide tools, in which case a variable-speed direct-current motor is used. Twelve feed changes are provided for feeding any tool at the rate of 0.0104–0.500 ipr of the table. Antifriction bearings, selected best to serve each purpose, are used. Gears up to 12 in. diam. are of heat-treated alloy steel; larger gears are of special alloy forgings or steel castings. Spiral bevel gears drive the table, and helical spur gears are used where advantageous. The complete table drive and spindle are automatically lubricated with oil pumped from a reservoir through a filter and then distributed to the working parts.



Courtesy King Machine Tool Co.

FIG. 9. A 100-in. Vertical Boring Mill, Equipped with Two Rams and a Side Head, Set Up for Turning a Large Cast-Iron Drum with Three Carbide-Tipped Tools.

The latest machines are driven directly by 25–50-hp motors, so that one or more sintered-carbide tools may be used at the proper cutting speeds. They are provided with pendant electrical control switches, so as to operate the rapid traverse (one for each head), a 5-hp elevating motor, and the 25–40-hp constant-speed main drive motor from a central position, Fig. 9.

SCREW MACHINES

Screw machines are quite similar in construction to the turret lathes, except that the head is designed particularly to hold and feed long bars so that parts, such as bolts, nuts, and screws, can be made from bar stock instead of from castings, forgings, etc. The operations performed by the tools of screw machine are similar to those of the turret lathe.

Some screw machines, Fig. 10, are used only for bar stock; others may be set up for bar-stock or chucking work. The Warner and Swasey universal turret lathe is set up for chucking work in Fig. 6, and for bar stock in Fig. 16.

A **classification** of the construction features of the screw machine follows:

1. Built only in horizontal types (one Swiss vertical machine).
2. Drive may be through step-cone pulley only for small fast work, Fig. 10; step-cone pulley and back gears; geared head, Fig. 16; or with multiple-speed motor mounted directly on the spindle, Fig. 15.
3. Cross slide may be hand fed by rack and lever, Fig. 10; by screw, Fig. 12; or by power feed through lead screw, Fig. 16.
4. Cross slide may have no longitudinal feed, being clamped in place to the bed, Fig. 10; hand longitudinal feed; or power longitudinal feed, Fig. 16.
5. Turret may be of the ram type, Fig. 10, or of the saddle type, Fig. 16.
6. Turret may be fed by hand only, Fig. 10, or by power, Fig. 16.

Typical Screw Machines

The **screw machine with plain head,** Fig. 10, represents a simple and inexpensive type. For any given setup, the bearing of the cross slide, which usually carries a forming tool in the front tool post and a cutoff tool held inverted in the rear tool post, is located longitudinally in the correct position on the ways by the hand adjustment wheel provided with a micrometer dial for accurate location. The bearing is then clamped to the ways by the cross-slide bearing screw. The cross-slide tools are brought into engagement with the work by the hand-feed lever. This motion is transmitted from the gear to a rack underneath the cross slide. Machines of larger size may have the gear and rack feed, or be provided with a hand-feed wheel operating a feed screw.

For a given setup, tools are placed in the various faces of the turret after which the turret-slide bearing is located and clamped to the bed. The turret slide is hand operated by the single lever. In this case the tool can be brought rapidly to the work and then fed into it by hand. As the turret slide is withdrawn and reaches the right end of its stroke, the turret is indexed one-sixth of a revolution, bringing the tools in the next face of the turret into operating position. The tools in each face of the turret may be fed by hand to the left against the work to any desired fixed position as determined by the setting of the ram stop rods. There is one rod or adjusting screw for each face of the turret. These rods are indexed about a center axis as the turret is indexed, so that rod 1 always determines the limiting feed motion of the tools in turret face 1.

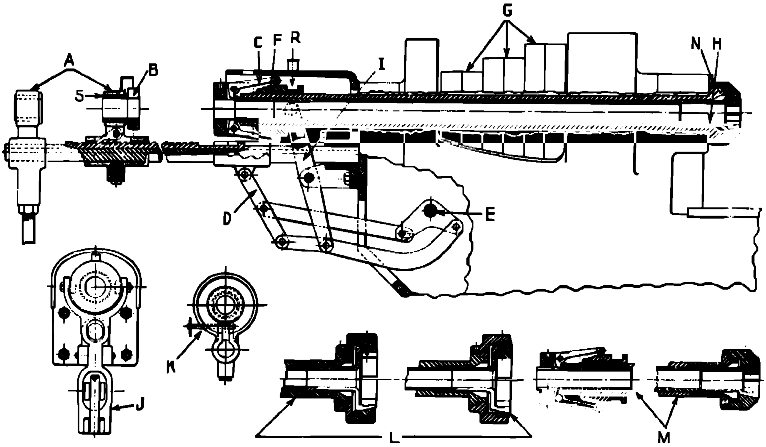
A, ram stop rods; *B*, round turret; *C*, turret slide or ram; *D*, turret-slide bearing; *E*, chip and cutting-fluid pan; *F*, hand longitudinal adjustment to cutoff slide with micrometer dial; *G*, cross-slide bearing binding screw; *H*, sight-feed oilers; *I*, hand-feed lever to cross slide; *J*, turret binding screw lever; *K*, bar feed and collet lever; *L*, lever for hand feed to ram.

FIG. 10. The Foster No. 1 Hand Screw Machine with Plain Step-Cone-Pulley Head.

This view shows the lever feed to the turret slide. Round bar stock up to $\frac{13}{16}$ in. diam. and 5 in. long may be machined.

This machine may be furnished with back gears so that a wider range of speeds is available, and a friction head so that the spindle may be stopped without stopping the step-cone pulley. Power feed to the cross slide and turret may be obtained if desired.

A standard set of tools for general work, usually furnished with each machine, consists of one plain stop gage, one chamfering tool, one roughing box tool, one finishing box tool, one releasing die holder, or one self-opening die head with four sets of chasers, one adjustable drill holder, one cutoff toolholder and blade, and one each of several round adjustable dies, together with one collet for round work and one feeding finger.



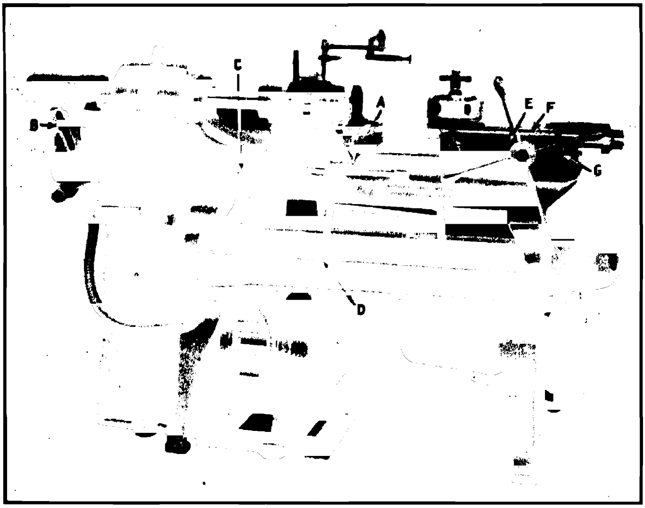
A, bar support; *B*, bar-feed collar; *C*, collet closing fingers; *D*, bar-feed linkage; *E*, bar-feed lever shaft; *F*, wedge; *G*, step-cone pulley; *H*, master collet; *I*, wedge linkage; *J*, vertical section at *R*; *K*, vertical section at *S*; *L*, increased capacity collets of the push-in and drawback type; *M*, drawback type collet and wedge; *N*, spindle nose.

FIG. 11. The Automatic Chuck, Bar Feed, and Operating Mechanism Used on the Foster Friction-Head, Geared-Head, and Plain-Head Screw Machines.

This shows the action on the spring-collet and bar-feed mechanisms as developed by the bar-feed linkage.

A vertical sectional view of the plain head of the larger Foster screw machine is given in Fig. 11. It has a single-lever type of chucking and feeding mechanism. The bar stock, usually purchased in lengths of 12–16 ft, is gripped by the collet *H*, passes through the spindle and through the supports at the left. The bar-feed collar *B* is attached by a setscrew to, and rotates with, the bar inside the flanged support. When the bar stock is to be led forward, the bar-feed and collet lever, the shaft of which is shown in section, is pulled to the right.

The wedge linkage causes the conical wedge *F* to slide to the right on the spindle, allowing the right end of the fingers *C* to close. This allows the sleeve or collet push tube within the spindle to move to the left, thereby relieving the pressure which forces the spring collet *H* into the conical spindle nose *N*. This, in turn, relieves the grip of the spring collet on the bar stock. At this instant, the bar-feed linkage moves the ratchet and feed collar *B* to the right, pushing the bar stock through the spindle. The feed lever is now forced to the left. This forces the wedge to the left which, in turn, forces the sleeve within the spindle and the collet to the right. This drives the collet into conical spindle nose, thereby gripping the bar stock. The ratchet is returned to the left to get a new grip on the bar-feed collar as the feed lever reaches the end of its stroke.



Courtesy Brown and Sharpe Manufacturing Co.

A, screw feed for cross slide; *B*, scale for feed length; *C*, chuck and wire-feed lever; *D*, rack feed or cross slide; *E*, turret-slide clamp; *F*, scale for gaging movements; *G*, turret-slide-bed clamps.

FIG. 12. The No. 2 Wire-Feed Screw Machine Arranged for Multiple-Speed Motor Drive.

Two belts, one open and one crossed, drive from the motor pulley to the two pulleys on the spindle shown in Fig. 14. The single lever on the head controls the clutch between these two pulleys for engaging forward or reverse spindle speed or for stopping. Machine is equipped with cutting-fluid circulating system. Bar stock up to $\frac{7}{8}$ in. diam. may be machined to a length of 5 in. Spindle speeds of 600, 900, 1,200, and 1,800 rpm are obtained. Five rates of power feed to the turret slide may be obtained.

When the ratchet has brought the feed collar *B* to the end of its travel to the right, it is returned by hand to the left-hand position by raising the small ratchet pawl. At the same time, the bar-feed collar is released and moved to the left on the bar stock where it is again attached. The linkage, Fig. 11, may be used with either push-out or drawback collets shown in the lower part of the figure.

The **wire-feed screw machine** as made for motor drive only, Fig. 12, has many semiautomatic features which make it possible to produce duplicate parts from wire or bars at extremely low cost.

The turret is of the ram type and operated by hand. The cross slide, which carries the forming and cutting-off tools, is clamped to the bed in the desired position and is fed transversely by hand with the rack and lever or by the feed screw. A screw stop is provided on the cross slide so that diameters may be duplicated.

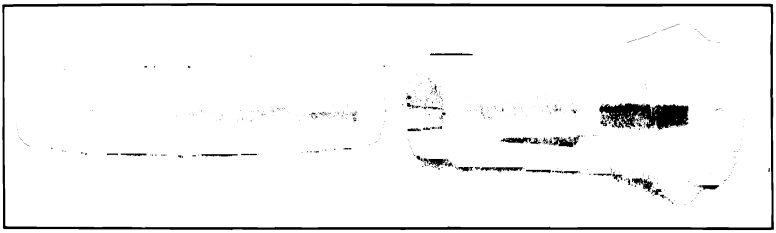


FIG. 13. A Brown and Sharpe Feeding Finger and Spring Collet.

Both are for $\frac{7}{16}$-in.-diam. stock for use in the No. 2 wire-feed screw machine. They are shown assembled in their operating position in the previous illustration. These collets, for different capacity machines, are made in various sizes for round, square, or hexagonal stock. Collet and feeding finger blanks also may be secured for special work.

In a belt-driven machine of this type, the spindle is driven directly by the cone pulley. A 3-speed countershaft is provided which gives a fast cutting speed, a slow thread-cutting speed, and a fast reverse speed for backing off solid dies or taps. When collapsible dies or taps are used, this reversing is not necessary. The six forward speeds are from 100 to 1,000 rpm directly in geometric progression and 398 to 1,000 rpm reverse.

Spring collets or chucks and feeding fingers for any size of bar stock within the capacity of the spindle are interchangeable in the spindle. A typical friction feeding finger and spring collet are illustrated in Fig. 13. It is often desirable to have master spring collets at *L*, Fig. 11, in which pads or jaws may be replaced when worn or when different sizes of the bar stock are used. The spring chuck or collet, Fig. 14, grips and drives the bar stock. The feeding finger feeds it forward during the feeding cycle as follows: the collet is opened, the stock advanced to the right by the feeding finger to the correct length as determined by a stop located on face I of the turret, Fig. 24, and the collet closed again, it being necessary only to press the feed lever *C*, Fig. 12, sufficiently to throw in the camshaft driving clutch. There are two cams on this camshaft located beneath the head, one of which actuates the sleeve *R*, Fig. 14, which opens and closes the collet. The other cam on the camshaft controls the movement of the feed tube, on the right end of which is attached the friction feeding finger.

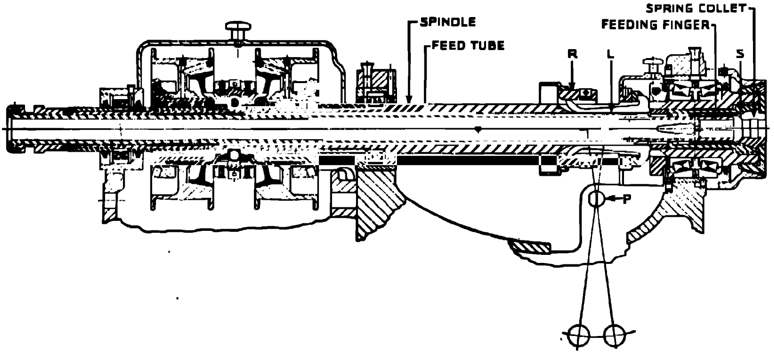


Fig. 14. A Sectional Drawing through the Spindle of the No. 2 Brown and Sharpe Wire-Feed Motor-Driven Screw Machine.

The bar stock extending from a rack at the left passes through the spindle, feeding finger, and spring collet.

A small **hand-operated screw machine** having the rotor of the multiple-speed motor mounted directly on the spindle is shown in Fig. 15. The stator is located in the headstock of the bed casting. Fans, which are attached to the rotor, draw the cooling air from underneath the headstock, circulate it through the windings of the motor and through the bearing housings, and expel it through the louvers at the front and rear of the headstock. The smaller lever on the headstock provides 4 spindle speeds of 600, 1,200, 1,800, and 3,600 rpm, respectively. The larger lever provides the forward spindle speed at the left and reverse spindle speed at the right, and operates the brake lever when pushed forward in the central position. The high spindle speeds permit the use of carbide and diamond tools for machining nonferrous materials, such as bronze, hard rubber, and Bakelite.

A universal turret lathe set up for bar work is shown in Fig. 16, and a similar lathe for chucking work in Fig. 4.

The single-lever speed selector on the head gives 12 speeds from 30 to 1,500 rpm. The feed-selector levers at the lower right of the carriage and turret give 9 feeds from 0.005 to 0.100 in. longitudinally for

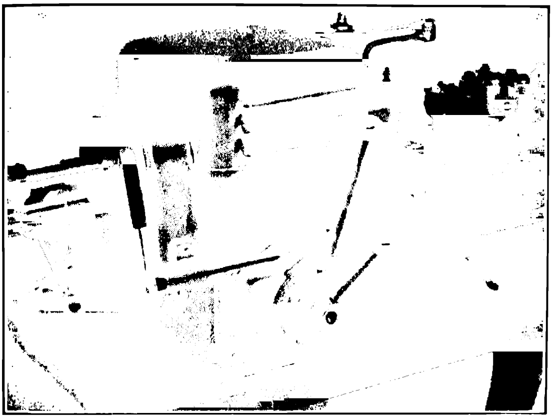
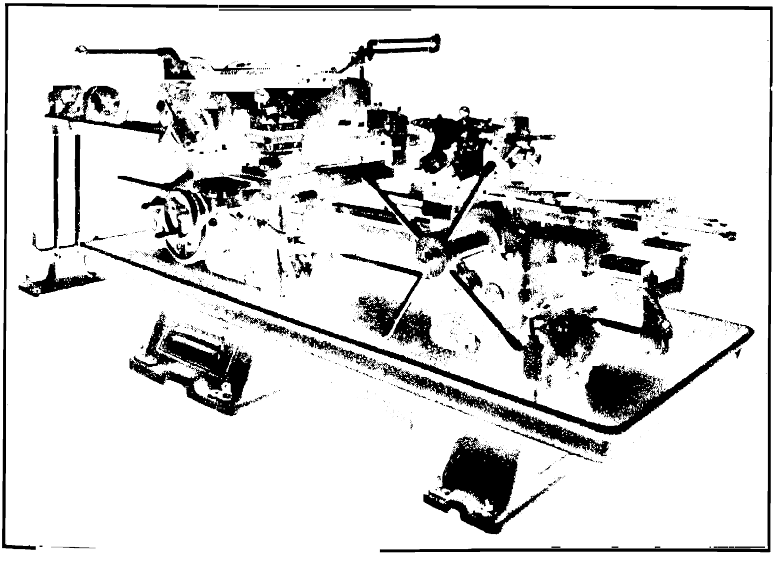


FIG. 15. A View of the Headstock of the No. 1 Motor-Spindle Warner and Swasey Ram-Type Turret Lathe.



Courtesy Jones and Lamson Machine Co.

FIG. 16. The No. 3 Jones and Lamson Ram-Type Universal Turret Lathe with Tools and Collet Chuck for ⅜-in.- to 1½-in.-diam. Bar Work.

the ram and carriage and 9 transverse feeds for the cross slide of half this amount. A 10- or 15-hp motor is mounted in the headstock leg cabinet and drives by a multiple V belt. A 4-way turret tool post is on the front cross slide, and 3 dovetailed tool blocks, each carrying an inverted tool, are mounted on the rear. Mechanical stops are provided for each longitudinal feed of the turret ram and for the longitudinal and transverse feed of the cross-slide carriage.

WORK-HOLDING DEVICES

Chucks for Turret Lathes

In turret-lathe work, the parts are held in a chuck of the **universal,** Fig. 4, **independent,** Fig. 7, or **combination** type, Fig. III–29. Chucks may have 2, 3, or 4 jaws which are opened and closed by hand with a T-handled square-key or socket wrench. The 2-jaw universal chuck is used more often on semiautomatic turning machines, Fig. XII–4, with the jaws formed to fit the work.

The **wrenchless** chuck, Fig. 17, is commonly used on turret lathes as well as on semiautomatics to reduce time and effort in chucking and releasing the work. Hydraulically, pneumatically, Fig. 18, or electrically operated chucks are more often used on semiautomatic turning machines and occasionally on hand-operated turret lathes.

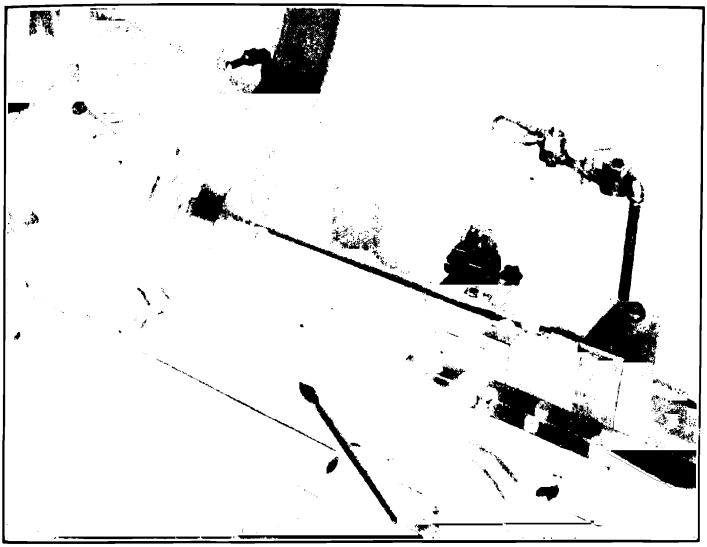
A **pneumatically operated** 2-jaw chuck and air cylinder are illustrated in Fig. 18. The inner faces of the cylinder and chuck are attached to the ends of the spindle by adapter plates. The chuck plate is fitted concentrically into the recess *D*.

The rod *V* of the chuck is connected by a shaft extending through the machine spindle to the piston rod *J*.

Chucking and Bar-Feeding Mechanisms for Screw Machines

The bar stock, from which parts are machined in a screw machine, extends through the hollow spindle of the machine, Figs. 11 and 13.

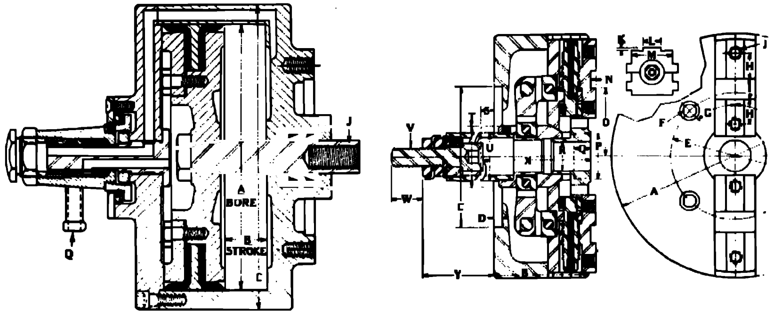
Figure 19 shows the **collet chuck** which may be used on engine or turret lathes for the production of parts in small quantities from bar stock. This permits the machining of larger bar stock than with the usual draw-in bar and collet attachment. The body of the chuck is recessed and bolted into the face of the adapter plate which, in turn, may be screwed onto the threaded end, or bolted to the face of the spindle. The chuck operation consists in drawing the collet, which encircles the bar work, back into the tapered opening of the chuck by drawing the threaded end of the collet into the threaded hole of the large disk in the rear of the chuck, rotated by means of a pinion hand-driven by the square-ended key.



Courtesy Warner and Swasey Co.

FIG. 17. The Gisholt-Barker Wrenchless Chuck as Used on a Warner and Swasey Turret Lathe.

This is a universal 3-jaw chuck with jaws shaped to fit the job. A shaft chucked at the left end is supported on a 3-roller center rest at the right end. The turret has been omitted, and the ram carries the roller rest, a single turning tool, and an adjustable blade counterboring tool. A similar counterboring tool seen between the two jaws is fed through the spindle to machine the left end of the bar. The work is chucked and released by simply moving the handle shown at the left, which is attached to the central, adjustable, nonrotating portion of the chuck.



Courtesy Logansport Machine Co.

FIG. 18. The Combination 2-Jaw, Model-B Chuck with Steel Body, Shown in Section at the Right, Arranged for Air-Power Operation by the Rotating-Type, Model-R, Self-Adjusting, Double-Acting Cylinder Shown in Section at the Left.

In Fig. 11, the spring collet is used in connection with the **bar-feed collar.** In Fig. 13, the **friction feeding finger** is employed to force the bar stock forward during the instant that the grip of the spring collet is released. This method is used in most automatic screw machines. The **spring collet and finger,** as shown in Fig. 14, are designated for any given machine by the size and shape of the bar stock used. The collets may be made for round, square, hexagonal, or any

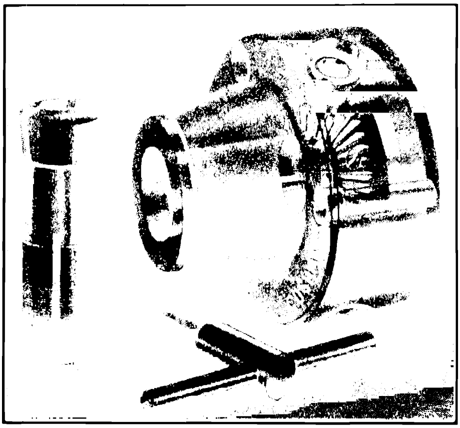


Fig. 19. The Cushman No. 15 Nose-Type Chuck for Collets.

Interchangeable collets for bar stock ranging from ⅛ to 1¾ in. diam. may be used.

other commonly used shape of bar. The collets are tapered in accordance with their use, such as the push-out type illustrated in the spindle section of Fig. 11, the drawback type shown as increased-capacity collets in Fig. 11, and the stationary type used in the spindle of Fig. 13. Spring collets and feeding fingers are made of hardened steel. The collets are split into sections and sprung apart before hardening so that the spring action tends to keep the opening slightly larger than the bar-stock size. The sections of the feeding finger are bent inward before being hardened so as to grip the bar stock. Some large-size bar lathes, such as the Brown and Sharpe Nos. 4 and 6, use a **roll-feed mechanism** instead of the feeding finger.

PRINCIPLES INVOLVED IN TURRET-LATHE AND SCREW-MACHINE OPERATIONS

In the small-lot production field where from 5 to 50 or even more pieces are made at one time, it is desirable that the least variety of tools be permitted to serve the greatest variety of work, both in chucking and bar-stock jobs. Four fundamental principles for increasing production on these machines are:

(*a*) Successive cuts on any surface.
(*b*) The use of combined cuts.
(*c*) The use of multiple cuts.
(*d*) Rigidity of tooling.

By taking **successive cuts** on a surface of the work, it is possible to rough, semifinish, and finish that surface to accurate dimensions and true shape at one chucking. A surface may be rough turned by a tool on the first face of the turret, and finish faced by a tool on the second face of the turret, or a hole may be originated by a twist drill, slightly enlarged and trued up by a rough-boring operation, and finished to size and shape by a finish-boring or reaming operation. If the hole already exists, it may be core drilled or rough bored, then semifinish bored or rose reamed, and finally finish bored or reamed. Also, a surface, whether internal or external, may be rough turned, finish turned, and threaded. Such combinations of successive cuts are almost infinite, and a detailed acquaintance with cutting tools is necessary in order that the most satisfactory results may be obtained. After the tools in a setup of this nature are properly adjusted, interchangeable parts can be turned out economically and quickly with comparatively unskilled labor.

By **combined cuts** is meant the taking of cuts simultaneously by tools mounted on the cross slide and those mounted on the turret. To illustrate: the drill mounted on turret face 1 of Fig. 21 is drilling while the tools mounted on the rear cross slide are facing.

By **multiple cuts** is meant the taking of cuts simultaneously with more than one tool from the same tool station. To illustrate: the multiple toolholder on turret face 1, Fig. 21, holds a drill, hub-facing tool, and rough-turning tool so that turning and drilling are being done at the same time. Multiple cuts also are being taken by the two facing tools on the rear cross slide.

Rigidity is insured by having wide, low saddles which support the turret by means of automatic or hand-operated ring binders for clamping the turret to the slide during machining operations, Fig. 6, and by means of overarm piloting bars which engage a bushing mounted on the headstock, Fig. 6. Gibs and slides should be snug.

Example Illustrating Selection and Arrangement of Tools in Turret-Lathe Work

An illustration of a typical turret-lathe setup is given to indicate the sequence of machining operations, as well as the advantages of multiple and combined cuts. The selection of speeds and feeds for this job also is discussed. This setup is similar to many found on machines of the hand-operated turret-lathe type or even the semiautomatic turret-lathe type, as discussed in the following chapter.

Figure 20 shows at *X* and *Y* a rough casting as supplied by the foundry from which the finished gear blank shown at *Z* is produced. The surfaces marked with heavy lines indicated by *A*, *B*, *C*, *D*, and *E* have been machined. The end of the hub opposite *D* is finished by facing in a subsequent operation, although it could be back faced at this chucking by using a sliding toolholder. In other words, the casting is to be turned, faced on two sides of the rim, faced on the front face of the hub, and the cored hole reamed. The casting has been designed to be as light as possible and yet permit the removal of sufficient stock on each machined surface to clean up and present an adequately finished surface.

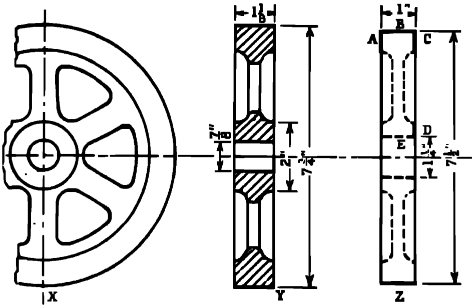


FIG. 20. The Gray-Cast-Iron Gear Blank Machined in the Following Illustrative Setup.

Views *X* and *Y* show side and section of the gray-cast-iron gear blank as furnished by the foundry. *Z* is the finished gear blank. The heavy lines indicate the surfaces machined. Tolerances on all dimensions are ±0.002 in., except on the bore, which is +0.001 in.

The operations are indicated in Fig. 21 in accordance with the position of the turret and cross slide. A list of tools is given with the speed of the work for that particular operation as well as the feed for the tools. The work is chucked by the operator in a universal 3-jaw chuck by expanding the jaws to engage the inner edge of the rim. The machine is started, and the turret is brought forward rapidly by hand until the tools are about to start cutting when the power feed is engaged. The cutting feed and speed are regulated for each face of the turret. As the turret advances, the following operations are performed:

First turret position, face 1, is equipped with a multiple turning head and high speed steel tools.

1. Drill the cored hole *E*, with 1⅛-in.-diam. 3-fluted drill.
2. Rough-turn outside diameter *B* with a turning tool, depth of cut 0.090 in.
3. Second rough-turn *B* with a second turning tool not shown, depth of cut about 0.025 in., leaving 0.010 in. for finishing tool. If only one roughing tool is used, the depth of cut will be 0.100 in., leaving 0.025-in. depth of cut for finishing.
4. Rough-face hub *D* with a facing cutter held in multihead at base of drill.

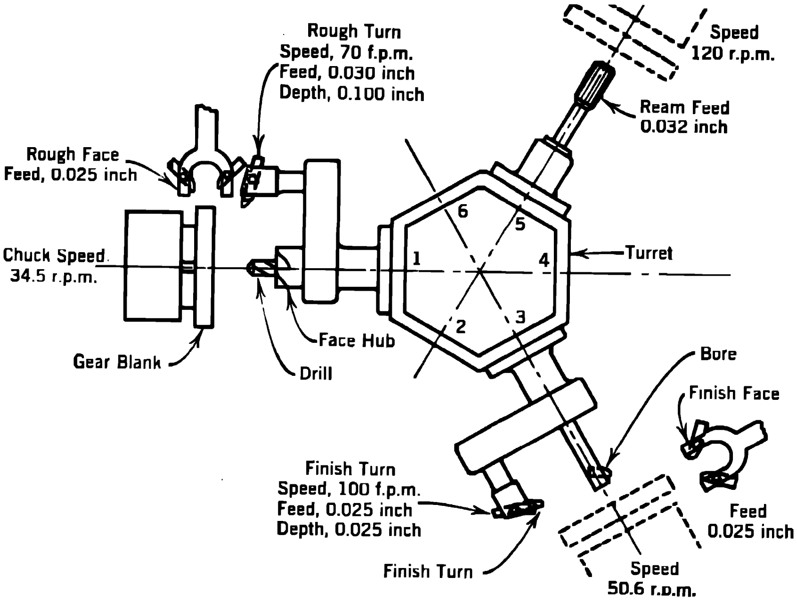


FIG. 21. The Illustrative Setup for Machining the Cast-Iron Gear Blank Shown in the Previous Figure on the Turret Lathe.

The second rough-turning tool not shown is not always used. It is good practice, however, as a lighter cut may be taken with the first turning tool, and also, less care is necessary in adjusting the first roughing tool which dulls quickly after it has been sharpened or replaced.

For the above operations, the permissible speed is governed by the turning tools rather than the drill or the hub-facing tool. A 1⅛-in. high speed steel drill would permit a speed of 270 rpm and a feed of 0.015 ipr of the work. The turning tool cutting on the 7¾ in. diam. at an assumed speed of 70 fpm for high speed steel tools is equivalent to 34.5 rpm. Therefore, the work should rotate at 34.5 rpm, which is slow but permissible for the drill.

If Stellite turning and facing tools are used, a cutting speed of 100–125 fpm would be satisfactory. If sintered-tungsten-carbide tools are used, the cutting speed might be approximately 300 fpm. These higher cutting speeds could be used on the periphery of the work without causing too high speeds for the high speed steel tools working in the bore.

The feed of the 3-fluted drill should be about 0.020 ipr of the work. The feed of the drill must be equal to that of the rough-turning tool. This may be up to 0.025 in. As the cutting speed of the drill is low, its feed is increased to equal that of the turning tool.

While the tools held in the turret are cutting, the two facing tools supported on the rear of the cross slides are fed forward so as to face the rim on the surfaces *A* and *C*. Each tool takes a depth of cut of 0.053 in. The speed of the work for these tools will be the same as for the turning tools of the turret, while the feed may be adjusted so that the operation is finished by the time the turret operation is finished. This feed will be approximately 0.025 ipr of the work, enough to finish the facing during the time required for turning.

A stop is provided so that, when the tools of the turret have been fed forward to finish all cuts, the power feed is disengaged. The turret is then withdrawn by hand, indexed to the next position, and fed forward to bring the tools against the work when the feed is again engaged. The machining time for this turret and cross-slide position is equal to that of the longest single operation.

Third turret position is also equipped with a multiple turning head. In this setup it is not necessary to use the second, fourth, and sixth positions of the turret. The tools of the third position are now brought into line, and the cutting feed is engaged. The cutting operations are as follows:

1. Finish-turn outside diameter *B* to 7.500 in. diam. with a turning tool; depth of cut is 0.010 in. or 0.025 in., as stated under 3 above.
2. Bore the drilled hole *E* to within 0.004–0.008 in. of size with a high speed steel single-point boring tool.
3. At the same time that the tools of the third turret position are cutting, the facing tools supported on the front of the cross slide are fed forward to finish-face the surfaces *A* and *C*, each tool removing about 0.010 in.

The speed of the work for this operation is limited by the turning and facing tools, which have a cutting speed of 100 fpm in view of the light finish cut taken on the 7.550 in. diam. giving 50.6 rpm. This cutting speed for the high speed steel tools on the periphery will give a cutting speed of 16.5 fpm for the boring tool, which is permissible.

The feed in the case of both the turret and cross slide is dependent on the finish. The feed could be increased because of the reduced depth of cut and still permit satisfactory endurance of the tools. A feed of 0.025 in. would be satisfactory for both the turret and cross-slide tools. Cast nonferrous or sintered-carbide tools will give correspondingly higher speeds.

Fifth turret position is equipped with a fluted reamer of high speed steel. The gear blank has now been roughed and finished on all surfaces with the exception of the bored hole *E*. As is customary, the last operation is to ream the hole to its finished size. As the speed of the reamer should be about half that of a 1¼-in. drill and the feed equal to twice that of the drill, it is seen that the work should rotate at a speed of 120 rpm and the turret should have a feed of 0.032 ipr of the work.

It is very often found in practice that, for some unlooked-for reason, the tooling speeds or feeds have to be modified. In this setup, for instance, it might be found that the combined and multiple facing and turning cuts for the first turret position require too much power, so that the speed or feed or both should be reduced. It might even be necessary to perform one of these roughing cuts in turret position 2, which would increase the machining time. Also, the speed might be increased for the third turret position; or, to get a better finish, the feed might be reduced. The feed of the reamer in the fifth turret position might be reduced to get greater accuracy. Again, if Stellite or sintered-carbide tools are used instead of high speed steel, the speed can be increased.

In **making a setup** for a turret-lathe or screw-machine part, the sequence of machining operations is first decided on. The tools are then selected and set up on the turret or on the cross slide to the best advantage, considering the tools and holders available. Standard tools should be used if possible, as special tools cost more and may not be usable on future work.

TOOLS AND TOOLHOLDERS USED ON TURRET LATHES AND SCREW MACHINES AND TYPICAL SETUPS

Each manufacturer of turret lathes and screw machines furnishes a wide variety of standard and special tools and holders for his machines of various types and sizes. Toolholders for turret lathes are, in general, quite different from those used on bar work. There are some, however, particularly in the universal type of turret lathe, which may be used interchangeably on bar or chucked work.

Turret-Lathe Tools

In operations involving chucked work, such as castings or forgings, typical operations performed are drilling, boring, counterboring, reaming, tapping, threading, rough and finish turning, facing and chamfering.

A wide variety of toolholders is necessary. These holders are designed so that standard tool bits, drills, reamers, dies, etc., may be used. An angular adjustable **single-cutter holder** which holds a tool bit or cutter for accurate boring, turning, chamfering, etc., is illustrated in Figs. 21 and 22.

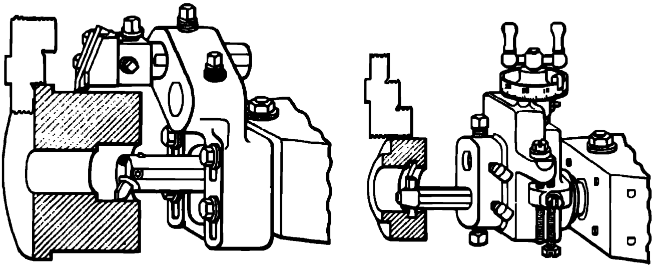


FIG. 22. At the Left, Adjustable Multiple-Turning Head with Flange Mounting on Turret, Showing the Adjustable Turning Toolholder and a Single-Point Boring Bar. At the Right, a Sliding Toolholder with Shank Mounting in Turret for Recessing, Back-Facing, etc.

Recessing or **slide tools** with shank mounting, Fig. 22 right, are used for accurate boring, recessing, facing, or back-facing work by tools on the turret. They may be provided with a large graduated dial on a cross-feed screw and adjustable positive stops.

Multiple-turning heads may be bolted to a face of the turret so that single-cutter toolholders can be mounted in any of several holes at different distances from the center in its face, either singly or several at one time for multiple cuts, as shown in Fig. 21, turret positions 1 and 3. Drills, boring bars, or reamers may be mounted in the central hole.

Cross-slide toolholders are of a variety of types, such as the single-screw tool post as used on engine lathes; cutter blocks in which one or more single-point tools may be clamped by setscrews, Fig. 21; and 4-way turrets in which 4 tools may be clamped and brought successively into operation, Fig. 4.

A flanged toolholder provides a rigid mounting on the turret face for shank-type tools, as shown on face 5 in Fig. 21. By means of standard bushings, tool shanks of various sizes may be accommodated.

Boring may be done in turret lathes by employing a single-point forged tool of the shank type; by having bits held in boring bars, as shown on turret face 3, Fig. 21; by having diametrally opposed cutters, the blades of which extend through slots in the boring bar; and by solid core drills or multiple-blade boring or counterboring tools, as illustrated in Fig. 23. In single-shank **multiple toolholders**, Fig. 23, various types of tools can be grouped for multiple cuts.

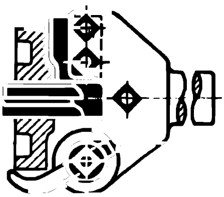


Fig. 23. A Multiple Toolholder, Showing Turning, Boring, and Facing Being Done Simultaneously.

Screw-Machine Tools

In working on bar stock in the screw machine, the operations commonly performed consist of centering, drilling, tapping, turning, chamfering, and threading with tools carried in the turret, and knurling, forming, and cutting-off with tools carried on the cross slide. In some instances, facing and turning are done with tools supported on the cross slide.

The flanged toolholder with the **combination stock stop and center** is used as illustrated on turret face I, Fig. 24. The center recedes into the stop for locating the length of the bar stock from the collet and is brought forward as shown for supporting the overhanging end of long bars in subsequent operations. The center may be replaced by a drill.

A **center drilling tool**, as illustrated on turret face II of Fig. 24, is used for centering the ends of shafts concentric with the outside diameter. The three rolls are adjusted simultaneously by a knob to fit the diameter of the bar.

An **end-facing tool**, as illustrated on turret face I of the second chucking, Fig. 24, is often used for facing or rounding the ends of bar stock before threading.

A **chamfering tool** is sometimes used to bevel the ends of work for starting turning operations, and for other end-rounding and chamfering work. These tools consist of a conical recess of hardened steel through the side of which the cutting edge extends.

A **single-cutter turner**, as used on turret face III of Fig. 24, has a single-point turning tool rigidly backed by a roller back rest. The radial force produced on the bar stock by the cutter is balanced by the roller, thereby preventing deflection of the overhanging stock.

A **roller-back-rest multiple-cutter holder** is made so that two or more cutters may be used for turning two or three diameters at once.

An **adjustable V rest** of hardened steel is sometimes used in place of the rollers, as shown in Fig. 25. When cutting soft metals, such as brass and bronze, at extremely high speeds, there is less wear on the V rest than on rollers, particularly in the absence of a cutting fluid.

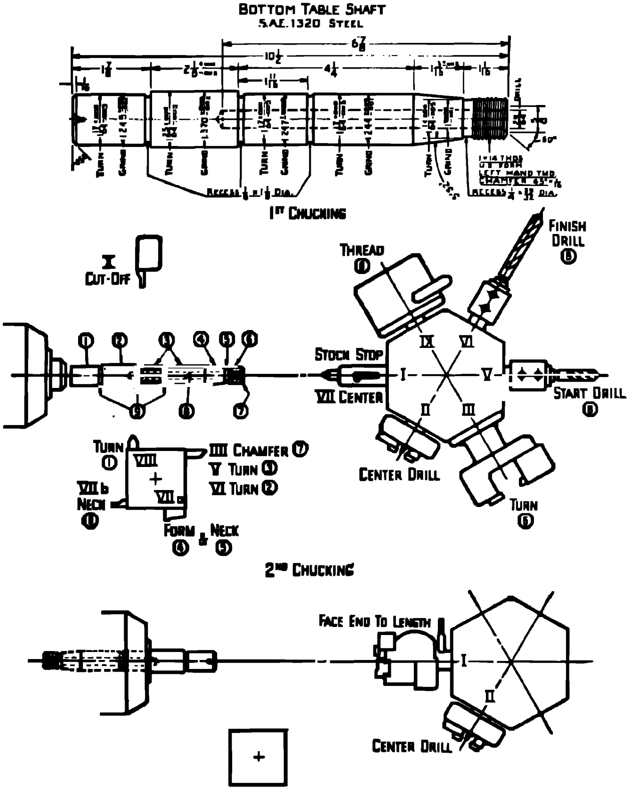


Fig. 24. A Bar Stock Setup on a Warner and Swasey No. 4 Universal 12-Speed All-Geared-Head Turret Lathe.

This machine is set up for machining the bottom table shaft of SAE 1320 steel. A drawing of the part is shown, together with the first chucking operation, in which the part is machined and cut from bar stock, and the second chucking operation, in which the cut-off end is finished. This setup was made with standard tools for producing these parts in lots of 100. The principle of combined cuts is illustrated. The production time per piece is 19 min, including all setup time. The Roman numeral adjacent to each tool indicates its sequence of operation.

Taper-shank drills may be attached to the face of the turret by being mounted directly in a **socket** which fits the bore in the face of the turret, or in a flanged holder bolted to the face of a hollow turret.

Often an **extended drill holder** with a sufficiently deep hole to assure a solid mounting for drills, counterbores, and the like is used, as illustrated on turret face V of Fig. 24. **Floating toolholders** of this type hold reamers so that a small amount of float may correct slight inaccuracies of alignment between the turret slide and spindle, as shown on face 5, Fig. 21.

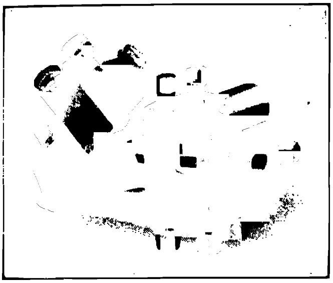


Fig. 25*A*. A V-Back-Rest Box Tool with Two Radial Cutters for Taking Multiple Finishing Cuts.

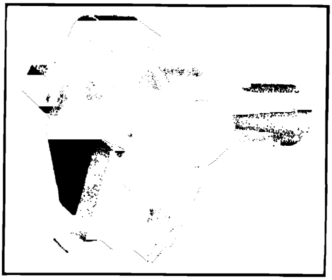


Fig. 25*B*. A Roller-Back-Rest Box Tool with Tangential Cutter with Ground-in Chip Breaker for Rough Turning.

Tap and die holders vary widely in design. Many holders are solid, involving a **slip clutch** so as to avoid tap or die breakage when overloads occur. Other tap or die holders are of the **releasing** type, in which the threading tool and forward end of the holder are released from the shank and allowed to rotate freely with the work when the thread is cut to proper length. The bar stock, however, must be reversed to withdraw the tool from the work.

Collapsing taps and self-opening dies withdraw the chasers from the work when the threads are cut to the required length.

Cross-slide form toolholders for holding circular-type or tangential-type form cutters are also used on the front or rear of the cross slide for cutting off and forming. A dovetailed **tangential form cutter** is shown on the front of the cross slide in Fig. 26. **A circular forming**

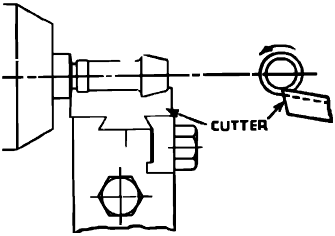
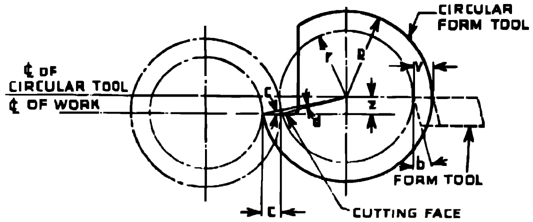


Fig. 26. A Dovetailed Tangential-Type Form Cutter, as Held in a Toolholder on the Front of the Cross Slide of the Warner and Swasey Universal Turret Lathe for Finish Forming a Spring Collet.

The cutting edge is given a relief and rake as indicated at the right.

tool is shown in Fig. 27. Form cutters of this type are ground to proper form and size after hardening. In all subsequent sharpenings, they are ground only on the face of the cutting edge, so as to retain the same relative position of the newly ground face and the work as was produced by the new cutter. Cutters of this type may be given an appreciable rake angle with the cutting point on the center of the work when turning copper and aluminum, a smaller rake angle for general work on steel and iron, and no rake angle when cutting brass or bronze (see *Screw Machine Engineering*, May, 1947, p. 57, and July, 1947, p. 62). They may be tipped with sintered tungsten carbide for special work on nonferrous materials.



Courtesy Illinois Tool Works.

FIG. 27. An End View of a Circular Form Cutter, Showing Its Position with Respect to the Work.

The cutting face C is on the center line of the work but a distance Z below the center of the cutter. A relation between dimensions and angles is as follows: (1) $V = R - r$; (2) $Z = R \sin c$; (3) $r \sin d = C \sin c$; and (4) $\tan d = \dfrac{C \sin c}{R - C \cos c}$.

CUTTING SPEEDS AND FEEDS FOR TURRET LATHES AND SCREW MACHINES

For **turret-lathe work** where the machines are designed for rigidity and for furnishing ample power, the **depth of cut** for the roughing cuts should be large and the **feeds** for roughing should be from 0.020 to 0.062 ipr. Usually in turret-lathe work, where castings and forgings are being machined, only sufficient metal is left on the surface to be machined off to permit the part to be cleaned up by a light roughing and finishing cut. When hard steel is used, the feeds should be reduced to 0.010–0.032 in., depending upon the grade of finish required and the depth of cut.

In forming or cutting-off operations in **screw machines**, fine **feeds** are used which range from 0.001 to 0.002 in. for wide forming tools, or where the tool is working under unfavorable conditions such as in cutting off. When the diameter of the work is small, down to $\frac{1}{16}$ in., or the tool very wide, much finer feeds, even down to 0.0001 ipr, must be used to prevent distortion of the work. Fine feeds with correspondingly high speeds are generally used to obtain the best surface finish.

Cutting speeds for use as a guide in setting up **turret lathes** are given in Table VII-2. These speeds should be increased for lighter cuts.

In **screw-machine work** where machining time is an important factor in the **cost** of the work, special materials have been developed which have free-cutting properties, as described under *Metals Machined*, Chap. VII.

Hollow mills and box tools of high speed steel operate at turning or drilling speeds of about 180 fpm as 100 per cent and normally at feeds of 0.006–0.012 in. for an 8-hr tool life.

Drills of the helical fluted type are used for most work on automatic machines. Straight fluted drills, or the helical type ground to zero rake at the cutting edge, should be used on brass to avoid digging in. For good results, the drill should be flooded with cutting fluid and the feeds moderate with a high peripheral velocity. Deep holes should be produced with drill speeds of 50–70 per cent with feeds of 0.003–0.007 in., or at 100 per cent speed by rotating both the work and the drill as this assists in removing the chips and getting the cutting fluid to the point of the drill.

Threading with chasers is carried out at 30–35 per cent of the rated speed. **Cutting-off** tools operate at speeds of 100–110 per cent of the rated speed with light feeds of 0.002–0.003 ipr. Form tools operate at 100 per cent of the rated speeds with feeds ranging from 0.0005 to 0.003 in.

Knurling tools operate at 100 per cent rated speeds with feeds of 0.015–0.030 in. for turret tools and from 0.002 to 0.006 for cross-slide tools. Drilling speeds vary from 100 per cent rated to 55–70 per cent rated for the deeper holes. Usually light feeds ranging from 0.003 to 0.007 in. are used. The above speeds for high speed steel tools would furnish a life between grinds of about 8 hr, during which a good surface finish is maintained.

A **cutting fluid** always should be used to increase tool life and to provide a better finish on the product. It should be such as to lubricate the moving parts of the machine and have no injurious effects upon the machine or work. It should be transparent so that the cutting action of all tools may be under continuous observation. A paraffin oil gives good results for brass. A mineral-lard oil is more often used on steel and is better when threading or tapping. A rich emulsion is often quite satisfactory for general work on soft steel, but a sulphurized oil is best for soft or ductile metals such as alloy steels, hot-rolled steels, Monel metal, and stainless steels.

Where much material is to be removed, carbide tools should be used where possible, particularly for cutting-off, turning, and forming tools. The various operations should be so arranged that the peak horsepower should not exceed the average horsepower developed during the cycle. A motor can carry a 50 per cent overload factor for a short period of time (*Screw Machine Engineering*, November, 1949, p. 32).

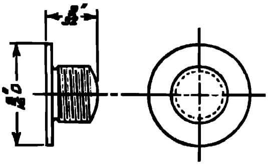


FIG. 28. The Filler Cap Produced in Accordance with Table 1.

There are many screw-machine products whose functional requirements permit the use of either brass or steel. A greatly increased rate of production due to the superior quality of brass, together with the high salvage value of brass scrap including chips, serves in the majority of cases to bring the total cost of producing a given piece in brass well below that of a part produced in steel. The example given in Fig. 28 shows the **relative cost** of making typical screw-machine products from brass and steel.

TABLE 1. COMPARATIVE COSTS OF ANACONDA FREE-TURNING BRASS AND SAE 1112 STEEL WHEN PRODUCING THE FILLER CAP ILLUSTRATED IN FIG. 28*

	Brass	Steel
Production per day	4,100	800
Work rpm	3,600	810
Material cost per pound	$0.146	$0.036
Scrap value per pound	0.083	0.00
Net material cost per M	2.83	0.90
Machine, tool, and labor cost per M	0.96	5.19
Total net cost per M	3.79	6.09
Reduction in net cost per M	2.30	(37.8%)
Brass price per pound at which total costs for brass and steel become equal	0.655	

* From A. C. Nielsen Co. Report No. AN-11-KZ.

QUESTIONS

1. Describe how an engine lathe may be converted into a turret lathe.
2. What accessories in addition to those added in question 1 are needed for machining bar stock?
3. Under what conditions would an engine lathe modified for turret-lathe work be used as compared with a standard turret lathe?
4. What is meant by a toolslide lathe and how does it function?
5. When would you use a turret lathe in preference to the toolslide lathe?

6. What is meant by a universal turret lathe?

7. What is the difference between the ram-type and saddle-type universal turret lathe, and which would you select for heavy-duty work?

8. What is meant by a cross-sliding head, and how does this influence the use of the regular cross slide?

9. What is meant by a cross-slide turret, and what is its use?

10. In screw-machine work two tools may be used on the cross slide, one in front of the work and one in the rear. Why is the tool in the rear inverted? Show by sketch.

11. Explain the principal differences as to use between a horizontal turret lathe and a vertical turret lathe.

12. Explain several different methods of obtaining spindle speeds in screw-machine work.

13. Explain two commonly used ways of feeding the bar stock in a screw machine.

14. What types of work-holding devices are used on turret lathes?

15. What is meant by successive cuts? Illustrate by drawing.

16. What is meant by combined cuts? Illustrate by drawing.

17. What is meant by multiple cuts? Illustrate by drawing.

18. What are some of the typical toolholders used on turret lathes?

19. Explain the difference between tangential and circular forming tools.

20. What is meant by free-cutting steel?

21. What are some of the materials commonly used in screw-machine work?

22. Under what conditions might it be cheaper to make parts of brass rather than steel?

23. Make necessary sketches to show the tooling setup for making a typical cap screw of hexagonal bar stock.

24. Compute the total number of 12-ft standard lengths of SAE 1112 steel required to produce 10,000 filler caps, shown in Fig. 28, if the cutoff tool $\frac{1}{16}$ in. thick is used and 5 per cent is allowed for butt ends and scrap.

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CHAPTER XII

AUTOMATIC TURNING MACHINES

DEFINITION

According to present usage, the term "automatic" is generally applied to machine tools in which the movements of all the cutting tools, as well as those of the material being cut, are actuated so that duplicate parts may be made repeatedly without the constant attention of an operator. If the machine tool simply performs a complete cycle of machining operations, but requires the attention of an operator to remove the part each time one is finished and to present an unfinished part to be machined, it is sometimes called an automatic, but is more generally known as a semiautomatic machine.

Even in the fully automatic machines, an operator is required to keep the machine provided with material such as bar stock or castings, so it may be presented automatically to the working tools. In this way, one operator may be able to keep several machines working continuously.

There are many types of automatic machines in commercial operation, such as printing machines, grinders, millers, gear cutters, broaches, die-casting machines, punch presses equipped with automatic feeds and ejectors, electric welders, and drill presses. Automatic turning machines, however, are confined to operations of turning, facing, drilling, boring, reaming, threading, forming, and knurling. The range of operations which may be performed by individual machines varies considerably.

CLASSIFICATION

Automatic turning machines, as developed at present, may be classified as follows:

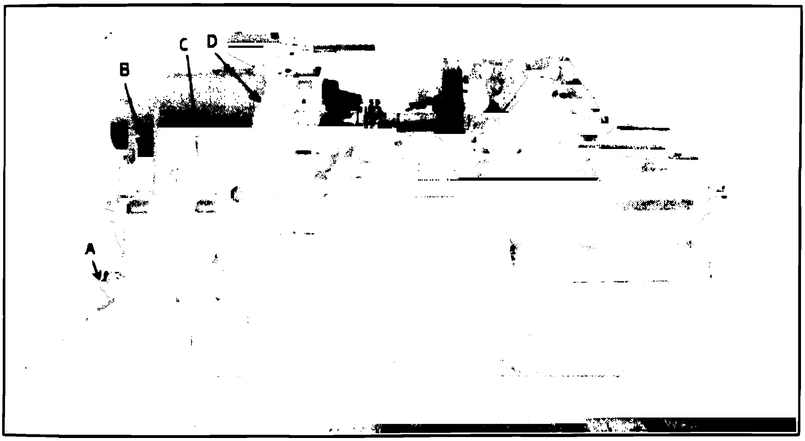
1. Automatic lathes
   (a) Turret or toolslide
   (b) Single or multiple spindle
   (c) Horizontal or vertical
2. Automatic screw machines
   (a) Single spindle
   (b) Multiple spindle

Automatic lathes include that group of machine tools which principally perform turning or facing operations automatically, on parts which are chucked or held on centers. **Automatic screw machines,**

on the other hand, are those automatics which produce finished or semifinished parts from bar stock. Both types are frequently provided with magazines or attachments to convey small rough or semifinished parts to the chuck of the automatic lathe or the collet of the screw machine.

AUTOMATIC TURRET LATHES

The **automatic turret lathe** is quite similar in make-up to the hand-operated type. It is usually provided with a front and rear tool post on the cross slide and a turret of either the ram or saddle type, having 4, 5, 6, or 8 faces.



A, fast- and slow-motion-control knob; *B*, fast-motion lever; *C*, start-and-stop feed lever; *D*, main-clutch lever; *E*, feed hand-cranking shaft; *F*, automatic-feed and speed-change levers.

FIG. 1. The Potter and Johnson 5-D Power-Flex Automatic Turret Lathe with Setup for Machining One End of the Malleable Cast-Iron Hub for an Automobile Rear Wheel.

Fifteen pieces are machined per hour per machine.

Figure 1 shows a **semiautomatic turret lathe.** The 5-faced turret is mounted on a saddle-type slide, the action of which is controlled by cams bolted on a cylindrical drum beneath it. A second drum, placed beneath the cross slide at right angles to the ways, controls the movement of the cross slide. Block-type tool posts are shown mounted on the front and rear of the cross slide. The chuck is mounted on the spindle, as in engine-lathe work.

There are four mechanical changes of speed and three selective changes of feed. The driving pulley speed is 1,200 rpm, the power being transmitted through helical gearing to the spindle. Other features are the Geneva mechanism, see Fig. 22, to revolve the turret at the end of its withdrawing stroke with automatic binding after indexing. The carefully aligned ways are of hardened and ground steel. The gears and shafts are chromium-nickel steel, and multiple disk clutches are employed. A typical setup for machining a cast-iron gear blank on this automatic lathe is shown in Fig. 2. This setup is quite similar to that in Fig. XI-21 in connection with turret-lathe work. The operations on the 1½-in.-diam. bore are core drill, rose ream, single-point-tool bore, and flute ream. The rim turning and facing tools may be of sintered carbide.

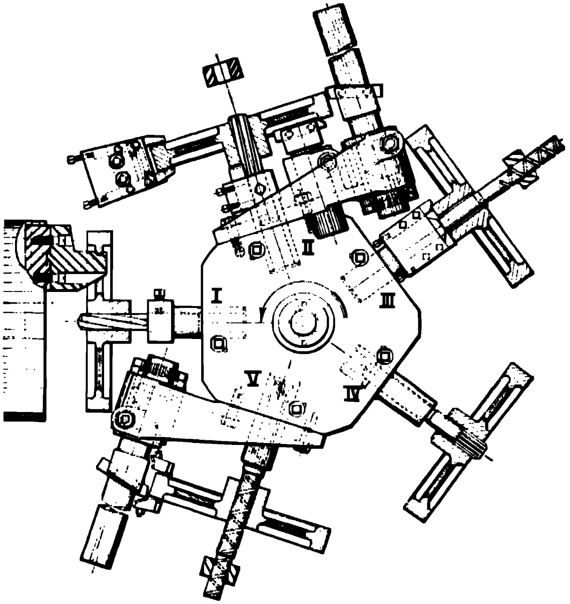


Fig. 2. A Setup for Machining a Gray-Cast-Iron Gear Blank in the First Chucking Position.

A Potter and Johnson 6-D turret-type automatic chucking and turning machine is used. The hub is cored. The outside diameter is 14½ in. and the face is 2 in. wide. A 45-deg bevel ⅛-in. wide is formed on the inner rim on the side of the hub projection. The sequence of operations is illustrated in the order of the turret face number.

A horizontal, semiautomatic, multiple-spindle chucking type of lathe is shown in Fig. 3. The 3-hp, 1,800-rpm motor located in the head end of the base drives to the single pulley shown at the left through a short belt. There are three tool spindles. Nos. 1 and 2, generally used for boring or turning, are arranged to receive boring and turning tools. Spindle 3, commonly used for threading, is arranged to receive the friction-drive tap or die holder or other tools.

The turret drum, cylindrical in shape, carries on its left end a square faceplate to accommodate four nonrotating chucking fixtures. The turret is mounted centrally in the large cap bearing. It is positioned horizontally in its bearing through the central threaded shaft which carries a micrometer index dial. The turret is indexed, moving the work from opposite one tool spindle to the next, by a Geneva-type mechanism located under the guard at the extreme right for gradually accelerating the turret and checking its motion without shock. The turret is automatically clamped in position after each indexing. The air cylinders, four in all, are contained within a single cylinder block mounted on the right end of the turret shaft and bolted to the turret. The air valves are automatically opened when the turret indexes from the finish position, permitting the finished part to drop into the work chute. The operator inserts a new piece and closes the air valve for that chuck. The horizontal bar for feed control is conveniently located in front of the operator. This type of machine gives very rapid production up to 1,800 per hr on small parts of brass, steel, or iron castings, forgings, and bar work, in which turning, facing, drilling,

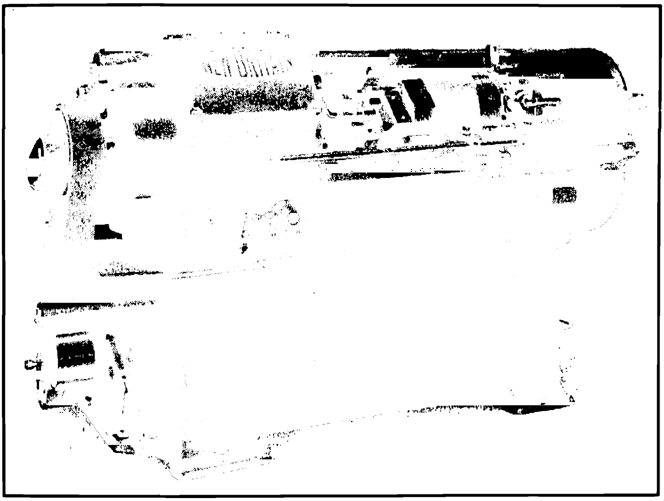


FIG. 3. The New Britain No. 12A Automatic Chucking Machine Used for the Rapid Production of Small Parts.

There are three tool spindles and four 2-jaw chucks. The chucks are arranged for air operation through rack and pinion.

boring, reaming, or threading operations are required. The time to machine a piece completely is equal to that of the longest single operation.

A close-up of an operation on a similar machine is shown in Fig. 4. The chucks are nonrotating but are indexed successively opposite the tools in the rotating cutter spindles.

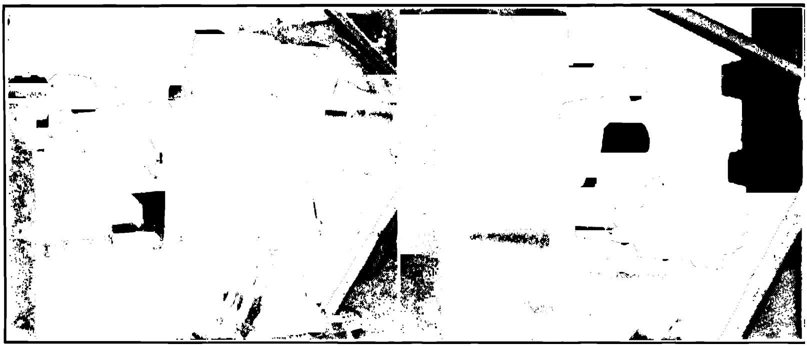


FIG. 4. A Close-Up of the Goss and DeLeeuw 8½-in. by 8-in. 5-Chuck Semiautomatic Turning Machine.

At the left is shown a view of the five work-holding 2-jaw chucks. The jaws are formed to fit the part and serrated to provide better gripping. They are opened and closed by the turnstile-handled socket wrench fixed opposite the loading position. At the right is shown a view of the various tools.

AUTOMATIC TOOLSLIDE LATHES

The single-spindle semiautomatic lathe of the **toolslide** or carriage type resembles a turret lathe without its turret, leaving the front and rear toolslides which are independently and simultaneously operated. Some designs have a third slide which may be located in the turret position. Each toolslide may carry one or several cutting tools.

The slide-type machine performs its cycle in much less time than the turret type, only single cuts or multiple cuts by a single pass, however, being taken on a surface, whereas the turret lathe performs successive operations on one surface. If two cuts, such as roughing and finishing, are required on a part and the toolslide-type machine is used, the roughing cuts are performed in one machine and the finishing cuts in a second.

This type of machining cycle permits castings to be heat treated between the rough and finish cuts, or allows the casting to cool off after the roughing cuts and before the finishing cuts.

The **Duomatic,** Fig. 5, has two independent carriages. Each carriage has a low rigid slide and is equipped with independent power rapid forward and return traverse, as well as power feed, to both the carriage and toolslide. Both carriages can be used simultaneously for turning or facing, or, as is usually the case, one carriage with its toolslide is used for turning and the other for facing. One large rotating feed screw drives each carriage. This feed screw provides the longitudinal movement of the carriage and drives the cross-feed screw of the toolslide. Six quick changes of speed are secured through the simple sliding gear headstock transmission by the manipulation of two levers.

FIG. 5. The Lodge and Shipley Duomatic Lathe Adapted to Quantity Production of Lathe Work Held between Centers, on an Arbor, or in Suitable Holding Fixtures.

The transposition of a pair of pick-off gears, easily accessible, gives six additional speeds.

A **setup** on the Duomatic lathe in which the tools are mounted on the front and rear cross slide for machining the fins on an air-cooled airplane engine cylinder is shown in Fig. 6. The material is SAE 3135 steel forged and heat treated. The cutting speed is 35 fpm, and the transverse feed of the front and rear slides is 0.004 ipr of the work. The tools used are rectangular bars of high speed steel properly relieved. The floor-to-floor time for machining this particular cylinder is 8 min. The cylinders are delivered to the lathe with the holes finished and all external straight surfaces and sides machined with the exception of the fins. The grooves are roughed out by the inverted tools on the rear cross slide and finished by those in front. The work is held and driven at the head end by a special three-section air-operated expanding arbor and on the tailstock by a revolving special center with three hardened and ground inserts.

Figure 7 shows another view of a tool **setup** on the Duomatic for machining an automobile cluster gear. The tools on the rear slide are fed transversely into the work, and those on the front slide are fed longitudinally to the left. The material is SAE 3250 steel drop forged. The cutting speed is 75 fpm, and the feed of the front slide 0.029 ipr. The feed of the rear slide is variable, starting with approximately 0.050 in. for facing. It is reduced to a finer feed for the heavy forming cut at the bottom with an ultimate die out and dwell to clean up. The tools used are made of rectangular bars of high speed steel, and the machining time floor to floor is 1.1 min. The cluster gear is delivered to the machine with the hole finished and the end face of the first and last gear machined. Two driving holes are drilled diametrally opposite each other in the face of the large gear for driving purposes. The cluster gear is supported at the head end on a special plug arbor, and the drive is through the medium of a special compensating-type driver having two pins which engage the drilled holes. A revolving plug center supports the work on the tailstock.

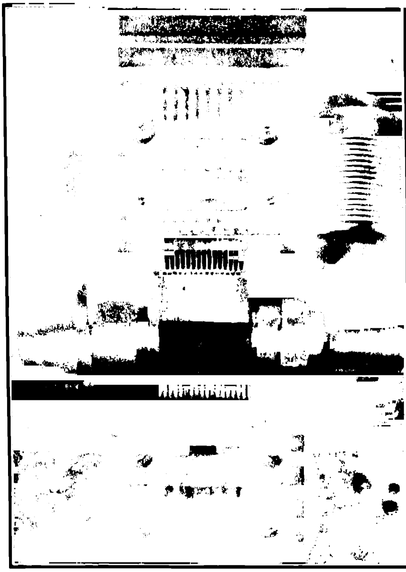


Fig. 6. A Plan View of a Tool Setup on the Lodge and Shipley Duomatic Lathe for Roughing and Finishing the Straight-Sided Fins of Air-Cooled Airplane Engine Cylinders.

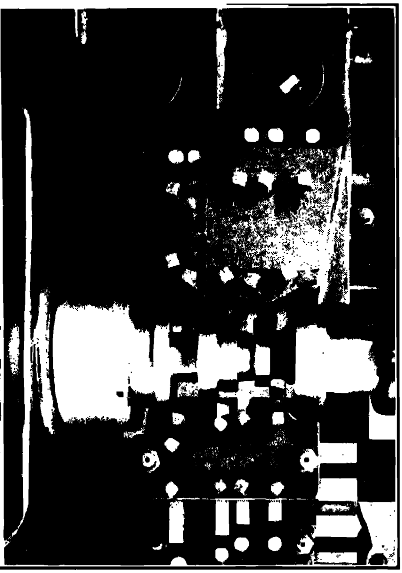
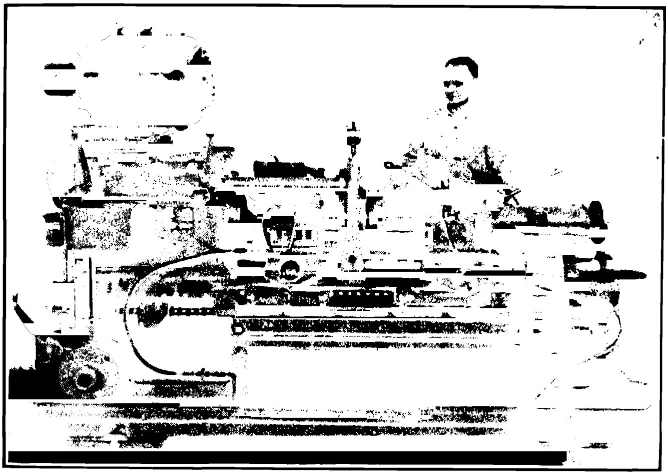


Fig. 7. A Plan View of a Setup on the Duomatic Lathe for Machining an Automobile Cluster Gear.

The **Fay automatic turning lathe,** Fig. 8, represents a horizontal-spindle machine of the single-spindle toolslide type. It has front and rear tool carriages or slides mounted on heavy cylindrical bars. The forward bar on which the front carriage is mounted is moved longitudinally by a cam on the master drum under the head. This operates the tools for turning operations. The front carriage may be fed longitudinally and at the same time given a tilting motion for taper or form turning by the shaped former-slide shown on the front of the bed.



Courtesy Jo s and Lamson Machine Co.

FIG. 8. A General View of the 12-in. by 45-in. Fay Automatic Lathe Tooled for Machining a Truck Rear-Axle Shaft.

Two front tool carriages and three rear or back-arm toolholders are provided. The forged shaft of 0.40-0.45 per cent carbon steel is 30¾ in. long and 2 in. diam. with a bevel-gear blank 4⅛ in. diam. on one end. The shaft, mounted on centers, is driven and steady-rested with the center drive attachment which receives its motive power from the headstock. The left carriage turns the taper, and the corresponding back arm forms and chamfers the thread diameter with a circular forming tool. The right front carriage forms and chamfers the back of the gear and the bearing diameter with a circular forming tool. The back arm on the tailstock end forms the face and back angles of the gear with a circular forming tool, and the middle back arm puts in the double undercut for grinding the bearing diameter at the back of the gear. By using 168 rpm for turning and 56 rpm for forming, a floor-to-floor time of 1 min 17 sec is obtained with a corresponding production of 37 finished shafts per hr, which is 80 per cent efficiency.

The rear toolholder mounted on the rear bar is made to rock in the transverse plane by drawing a supporting former-slide to the left. The former-slide is moved independently by separate cam on the master drum.

Automatic loading is applied to production turning machines in Fig. 9. A cast-bronze bushing, previously broached, oil grooved, and milled to length, is loaded in the supply chute to be turned concentrically on the outside diameter. After being turned, the work is ejected from the spindle into a take-away chute.

A pneumatic cylinder, Fig. 9, on the right end of the spindle operates the expanding split mandrel for gripping the bushing while it is being turned. The horizontal cylinder on the headstock strips the bushing from the mandrel after it has been turned. The cylinder on the end of the tailstock loads the bushings from the chute onto the driver. The fourth cylinder on the front of the headstock operates the rapid traverse of the carriage as a booster cylinder to assist the feeding cam in the quick return of the carriage unit. In subsequent operations, the ends are faced and chamfered and the casting is cut in two to make wrist-pin bushings.

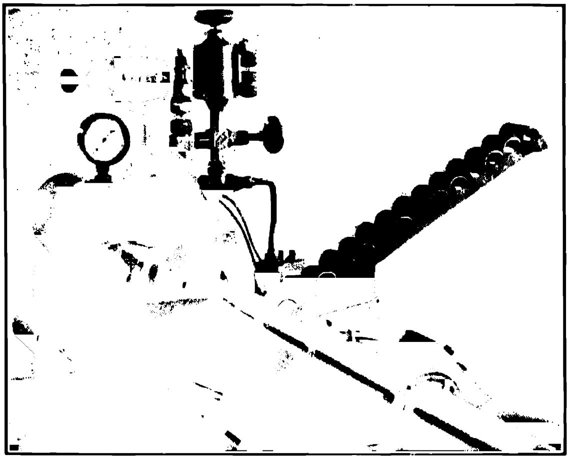


FIG. 9. A Close-Up View of the Lo-swing Model P Automatic Lathe Setup to Turn Bushings.

The arrangement of the chute which supplies rough stock to the spindle, the front longitudinal toolslide, and the Logan pneumatic chuck attachments are shown.

A **vertical multiple-spindle, toolslide** turning machine having 6 chucks and 5 working spindles with corresponding toolslides, Fig. 10, is one of the most productive machine tools of the turning and facing type. The Mult-Au-Matic type D is made in 3 sizes of 8-, 12-, and 16-in. swing with either 6 or 8 spindles. Forty-one changes of speed, from 33 to 300 rpm, and 82 rates of feed from 0.0056 to 0.246 in. per rev are available. The type K Mult-Au-Matic is a high-speed development of the standard machine with 6, 8, 12, or 16 spindles. It operates up to 883 rpm with 41 speed changes and 82 feeds. Double indexing may be employed, providing a double setup or to give two loading stations to permit first and second chucking of work.

The fundamental idea of the Mult-Au-Matic is the dividing of machine work on any given piece into operations and work units, and meeting these mechanical requirements by balanced simultaneous processing on each of its multiple spindles. The operator stands at station 1, the loading and unloading point, where the chuck is stationary. All other chucks and slides are working during the reloading time. The slides at each station are set up to correspond with the tooling of one face of a turret. The work, after being chucked, is automatically indexed successively to all stations and finally returned to the unloading station. It passes through the various stages of machining and is completed when returned for unloading, Fig. 11.

Several types of heads are provided for different types of operations. There is a plain vertical head in which the tools are fed vertically, a compound-horizontal head in which the tools may be fed first vertically and then horizontally, a universal head in which the tools may be fed vertically, horizontally, or at any angle, and a double-purpose head with which combined cuts can be taken, such as drilling, turning, and facing.

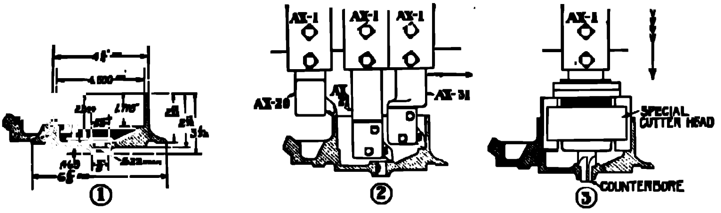
Courtesy Bullard Co.

FIG. 10. The Bullard 12-in. 8-Spindle Type D Mult-Au-Matic.

With one loading position at the T-wrench and seven simultaneously working stations for multiple and successive cuts, parts are finished at each indexing in a time equal to that of the longest single operation.

SPECIAL-PURPOSE SEMIAUTOMATIC LATHES

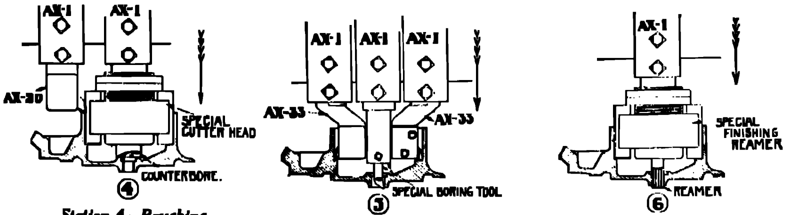
The **semiautomatic duplex-type crankshaft lathe,** Fig. 12, has been designed for machining one pair of crankpins at a time and for machining two or more line bearings at a time on multiple-throw crankshafts. This lathe is suited for machining crankshafts for automobiles, tractors, etc. In factories requiring a large production, one lathe is provided



Station 1—Loading

Station 2—Roughing F.P.M. 50 Feed .0162

Station 3—Roughing F.P.M. 77.9 Feed .0244



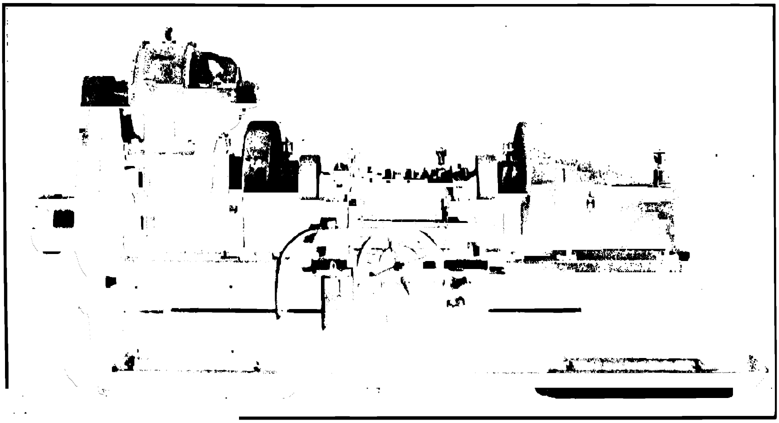
Station 4—Roughing F.P.M. 77.9 Feed .0244

Station 5—Truing F.P.M. 77.9 Feed .0415

Station 6—Finishing F.P.M. 58 Feed .06

FIG. 11. A Series of Operations Required to Machine a Small Cast-Iron Motor Body on a Mult-Au-Matic Equipped with Individual-Type Toolholders Which Permit Flexibility in Change of Setup.

The cutting time of the longest operation is 41 sec; the indexing and head traverse time is 8 sec, making a total time per piece of 49 sec.



Courtesy Wickes Brothers.

FIG. 12. A 34-in. Swing Semiautomatic Duplex-Type Crankshaft Turning Lathe.

This machine is set up for turning simultaneously one pair of pins or two or more line bearings on multiple-throw crankshafts. Both ends of the crankshaft are held in pot chucks, each pair of chucks so designed that the pins or bearings being machined rotate on center.

set up for each operation, i.e., for each pair of pins or for each line-bearing operation. If the production required is small, only one lathe may be provided with several sets of interchangeable tools so that all operations required on the crankshaft may be performed in turn on the same lathe. Pins and line bearings on crankshafts having a stroke up to 8 in. and an over-all length of 6 ft may be machined. A production per hour of 20–35 pairs of pins or 10–25 crankshafts requiring a checking operation is obtainable.

The machining operations on the crankshaft forgings, such as a 6-throw, 7-line bearing crankshaft, would be somewhat as given below after the ends have been drilled and countersunk. The shaft is mounted on center and securely clamped in the pot chucks by means of the self-adjusting drivers. Two sets of tools work on each pin or bearing. Each set mounted on the rear slide consists generally of two cutters which remove most of the metal from the face of the cheek and ends of the pin or bearing. A single wide-face cutter is mounted on the front slide for cleaning up the bearings. The front and rear tools are fed toward the work simultaneously. The machining operations are as follows:

1. Cheek, turn, and fillet Nos. 3, 4, and 5 line bearings, using Wickes 34-in. duplex-type crankshaft lathe as shown in Fig. 12.
2. Form the stub and flange ends; cheek, turn, and fillet Nos. 1, 2, 6, and 7 line bearings, using a Wickes center-drive-type crankshaft lathe.
3. Finish-turn Nos. 1, 2, 3, 5, 6, and 7 line bearings on the duplex-type crankshaft lathe.
4. Cheek, turn, and fillet Nos. 1 and 6 pins on the duplex lathe.
5. Cheek, turn, and fillet Nos. 2 and 5 pins on the duplex lathe.
6. Cheek, turn, and fillet Nos. 3 and 4 pins on the duplex lathe.
7. Finish-turn outside diameter and back of flange on a 20-in. rapid-production lathe.

The **center-drive type** of crankshaft lathe used in the second operation is quite similar to the duplex type, except that the crankshaft is mounted on centers at each end and driven by a center-drive gear closed about the crankshaft as in Fig. 8. The large herringbone gear, which circumscribes the self-adjusting driving dogs which engage the center main bearing, has a segment which may be raised for loading and unloading the crankshaft. The center-drive type of lathe permits the machining of both ends of the crank as well as the two line bearings at each end.

The car-wheel lathe manufactured by the Niles-Bement-Pond Co. employs the center drive so that the two wheels on the axle can be turned simultaneously, just as the two ends of the shafts are being machined in the Fay automatic lathe, Fig. 8.

AUTOMATIC SCREW MACHINES

Automatic screw machines are designed to produce parts from bar stock. Some may be equipped with a magazine so that a second operation may be done on the parts previously made from bar stock or even small castings or forgings. Machines of this class are used for such a variety of operations and operate on so many different principles that space will permit the discussion of only the most important features and descriptions of a few representative types. Most machines of this type may be equipped with special attachments for doing secondary or finishing operations such as slotting the head of a screw, drilling a cross hole in the parts, rear-end drilling or threading, burring. Magazines and attachments are discussed later. Unless the quantity produced is sufficient to warrant the cost of special tools and the setting up of the attachment, it is cheaper to do these operations later on another machine.

Tools

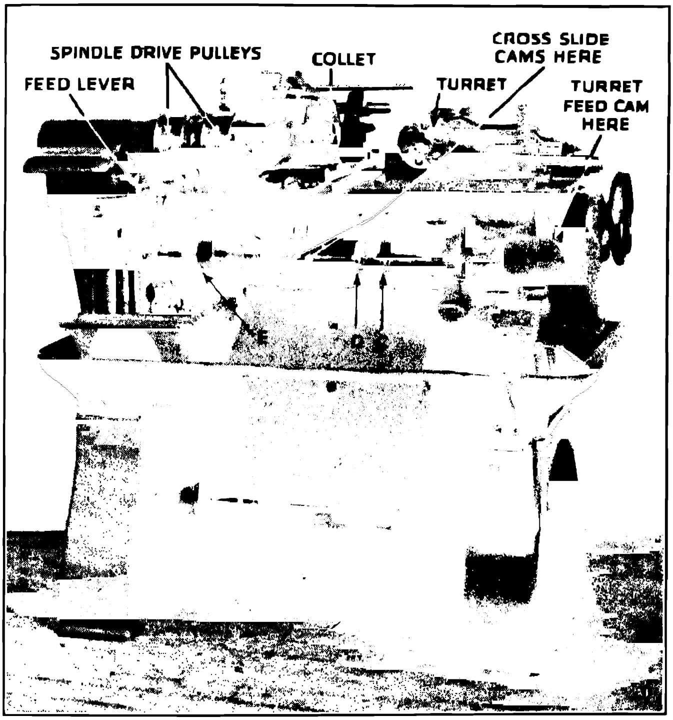
All machines are regularly equipped with a large variety of toolholders to accommodate standard tools such as drills, reamers, taps, dies, shell mills, turning tool bits, straight or circular formed tools, and cutoff tools, as described in Chap. XI. Many operations require additional special tools for forming, or even attachments and fixtures, depending upon the nature of the work.

Single-Spindle Automatic Screw Machines

Of the number of types of single-spindle automatic screw machines, a few typical ones are presented. Figure 13 shows the No. 2, single-spindle automatic screw machine which takes bar stock up to 7/8 in. diam. and feeds any length to 4 in. This type of machine is made in several sizes. The smallest machine, No. 00G, takes stock up to 5/16 in. diam. and feeds any length to 2 in. The No. 0 takes bar stock up to 1/2 in. diam.; the No. 4 up to 1 1/2 in. diam.; and the largest machine, the No. 6, takes stock up to 2 in. diam.

The spindle of the overhead-driven type, Fig. 13, is driven directly by wide belts on the two pulleys, one pulley for forward motion, and the other for reverse as required in threading or for slow-speed operations. A clutch between the two pulleys is keyed to the spindle. It may engage either pulley and provides a rapid change in direction of the spindle. See Fig. XI-14.

A separate belt drives from countershaft to the **feed-drive pulley on the left end of the rear feed shaft.** This drive runs continuously. A clutch in the feed shaft may be disconnected by the feed lever, shown in Fig. 13, stopping all motion in the machine but the rotating spindle. When the feed clutch is engaged, the feed shafts at the rear, right end, and front rotate. Clutches on the rear feed drive shaft are controlled through connecting levers by trip dogs placed on the graduated carriers *C*, *D*, and *E*. A trip dog on the left side of carrier *E* may cause the clutch between the two spindle pulleys to reverse or stop the spindle. A dog on the right side of carrier *E* may change speeds of the two-speed countershaft. Dogs on carrier *D* actuate a cam so the bar stock is released by the collet, fed forward, and again gripped by the collet. Dogs on carrier *C* determine the time of indexing the turret.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 13. The Brown and Sharpe No. 2 Single-Spindle Automatic Screw Machine of the Belt-Drive Type Arranged for Motor Drive.

Tools located on the front and rear cross slides are actuated by disk cams mounted on the front feed shaft as indicated in Fig. 13. The turret, which is mounted on a slide, is given all forward motions for quickly presenting the tools to the work and the cutting feeds for all turret positions by the disk cam on the right-end feed shaft. These three cams are made specially for each job, Fig. 15.

The **automatic rod magazine** is available so that bar stock is taken from a magazine and fed through the feeding finger and collet to the desired position. The operation of the magazine is timed in correct relation to the automatic functions of the machine. When one rod is used up, the machine, except for the spindle, is automatically stopped. A clutch is simultaneously engaged, and the mechanism of the magazine is set in motion. This feeds a new rod into the collet, ejecting the remaining piece of the previous rod, and the machine again is automatically set in operation. The magazine may be restocked at any time without interfering with the operation of the machine or magazine.

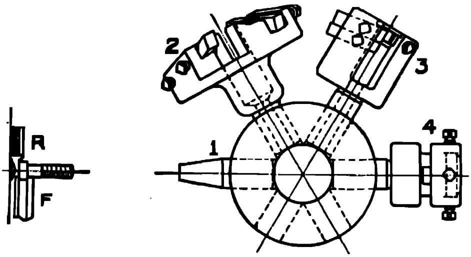


FIG. 14. Tool Setup for Making Brass Screws in the No. 2 Brown and Sharpe Automatic Screw Machine.

The spindle speed is 1,200 rpm, and the production is 92 pieces per hr. The turret operations are feed stock to stop 1; rough-turn with the 2-blade balanced tool 2; finish-turn with box tool 3; thread with solid die 4 (reverse spindle to withdraw die). Cross-slide operations are: form screw head with front tool *F* after 2, and cut off and form end with tool *R* after 4.

The Brown and Sharpe automatics are manufactured in **three types,** such as the threading machine as described above, the turret forming machine, and the cutting-off machine. In the **turret forming machine,** the spindle-reversing mechanism of the threading machine is eliminated. This gives a simplified form of automatic for work not tapped or threaded. The **cutting-off machine** is further simplified to handle work which does not require the reversal of the spindle. A single toolholder slide replaces the turret and its slide. These simplifications provide an automatic machine equally as efficient as the regular automatic screw machine but limited to cutting-off or forming work.

Figure 14 shows a typical setup in the Brown and Sharpe automatic screw machine. The finished screw is shown at the left with the front forming tool *F* forming the head and the rear cutting-off tool *R* cutting off the screw and rounding the end of the bar.

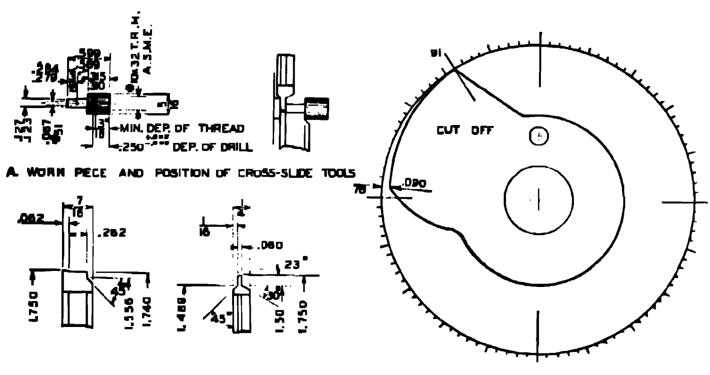
Figure 15*A* shows the manner in which the **cams are laid out** for a given job to be done on the Brown and Sharpe automatic screw machine. Three cams are required, one for the turret slide and one each for the front and rear cross slides. The portion of the circumference for each cam is a direct function of the number of revolutions of the work required by that operation, as indicated in the list of operations given in the figure. The small hole is drilled in the left end of the part, on the same machine, by the use of the burring attachment. After the forming, knurling, drilling, and tapping operations are performed, the piece is picked up by the transporting arm as it is severed from the bar. It is then transferred to the burring attachment where this second operation is performed without any loss of production time.

A number of types of auxiliary attachments may be used on these machines to increase greatly the scope of work which otherwise would require the use of an additional machine. These attachments are of two classes. The first performs secondary operations on the piece in a separate mechanism after it has been cut off. To this group belong index drilling and operations on the cutoff end of the work as screw slotting, rear-end threading, burring, and other light operations, and bent-shank tapping. The second class consists of those attachments used on the machine as tools for special work or auxiliaries to the regular tools, all of which operate from the turret or cross slides in conjunction with the regular equipment such as the cross drilling, drill rotating, tap or die revolving, combination drilling and tapping, helical-gear generating, extra vertical slide.

The **cross-drilling attachment** mounted on the rear cross slide rotates a drill by a small belt directly from the countershaft. The work spindle is stopped during the cross-drilling operation, requiring additional time.

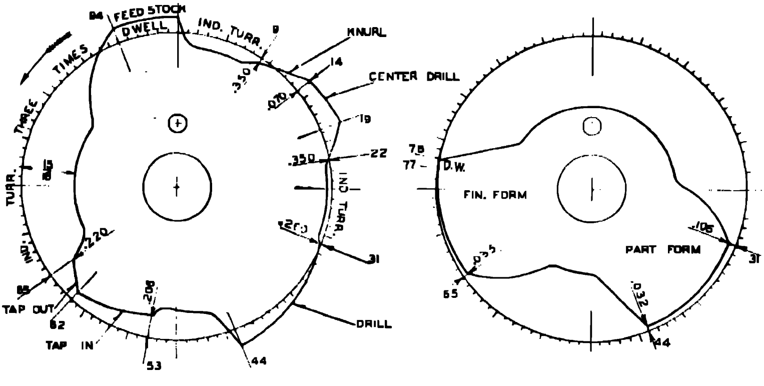
A **combination drilling and tapping attachment** has a drill and tap supported in bushings in the turret. The tap is driven directly from a center bevel gear which, in turn, is driven by a belt from the countershaft. The tap or die rotates in the same counterclockwise direction as the work, but slower, the combination of the two speeds giving a desirable threading speed. To withdraw the tap from the work, its speed counterclockwise is increased so as to be greater than that of the work. The drill is rotated from the tap gear which causes it to turn in a direction opposite to the work. This results in a higher cutting speed for the drill.

The **Swiss-type** automatic screw machine for the rapid production



B. THE CARBON-TOOL-STEEL CROSS-SLIDE TOOLS

C. CAM FOR REAR-SLIDE CUT OFF TOOL



D. CAM FOR TURRET SLIDE

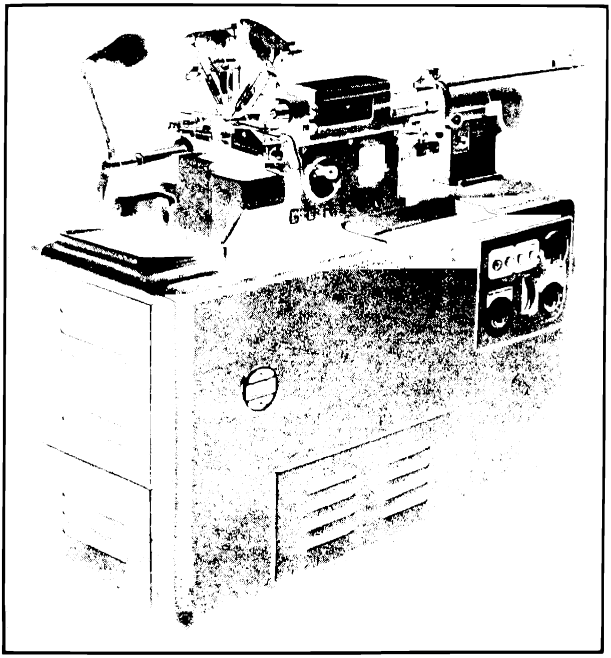
E. CAM FOR FRONT-SLIDE FORMING TOOL

FIG. 15*A*. The Cams, Formed Tools, and Operations for Machining a Knurled Brass Insert on a No. 00G Brown and Sharpe High-Speed Motor-Driven Automatic Screw Machine.

Round brass stock cold-drawn to $\frac{5}{16}$-in. diam. is used with a No. 00 spring collet and feeding finger. The spindle speed is 1,500 rpm forward and 5,000 rpm reverse. The spindle runs reverse for the carbon-tool-steel cross-slide tools. The driving shaft rotates at 240 rpm with change gears having teeth as follows: on the driving shaft, 40; first on the stud, 60; second on the stud, 52; and on the worm, 30. Production time per piece is 3.25 sec, equivalent to 1,108 pieces per hr gross.

Spindle Revolutions	*Order of Operations and Tools*	*Feed per Revolution in Inches*
24	Index turret	0.020
37	Knurl and center drill L.H. 0.250 in diam.	0.040 and 0.005
24	Index turret	
35	Part form with front slide	0.0019
24	Index turret and reverse spindle	
8	Tap in, 10–32 thread	
	Reverse spindle	
8	Tap out, then index turret three times	
35	Finish-form with front slide	0.001
35	Cutoff with back slide	0.0025
24	Feed stock to stop	

of long, slender precision parts is illustrated in Fig. 15*B*. The bar extends through a stationary, carbide-insert guide bushing located near the point of the cutting tools to give minimum overhang of the work with resulting high accuracy. The bar stock is rotated and held in the headstock which slides by cam action on the bed for longitudinal feed. By synchronizing this longitudinal-feed movement with cams which control the radial feeding of the tools, any desired shape of work can be turned with single-point tools. Each of the five radially placed tools may be adjusted with micrometer screws for axial and radial positions. The speed of the camshaft for tool feed is infinitely variable, allowing from 12 to 720 pieces per hr with low-range cam feeds or 20–1,440 pieces per hr with high-range cam feeds, adjusted by a Graham variable-speed unit. The cam feeds indicated on the lower left dial are obtained by turning the knurled wheel in the center of the control panel. The spindle speeds are infinitely variable



Courtesy George Gorton Machine Co.

FIG. 15*B*. The Gorton 16-B Automatic Screw Machine (Swiss Type).

This machine, designed for turning a wide range of accurate, small-diameter, long, slender parts at high speed, involves a principle of the cutting tools being fixed in a head clamped on the bed with a headstock rotating and feeding the work to the toolhead as it slides on the bed by cam action.

throughout the range from 750 to 10,000 rpm by means of a Reeves variable-speed unit driven by a two-speed motor. The spindle speeds are selected by turning the handwheel in the upper right of the panel and are indicated on the dial below. A section through the spindle headstock and toolhead is shown in Fig. 15C. Bar stock up to $\frac{7}{16}$ in. diam. can be machined to a length of $2\frac{3}{4}$ in. The bar must be round within a total of 0.0003 in. and uniform throughout its length within -0.0005 in. For each setup five cutting tools, one bushing and collet, and five cams are needed. One cam is for bar feed, a second cam is for the front and rear station, while three cams are for the three upper tools.

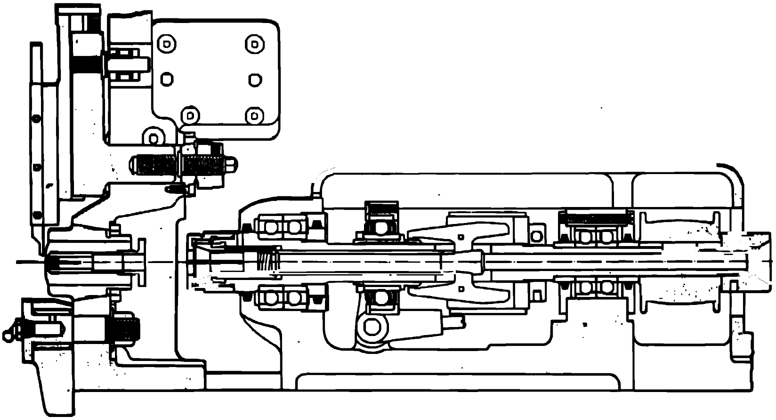
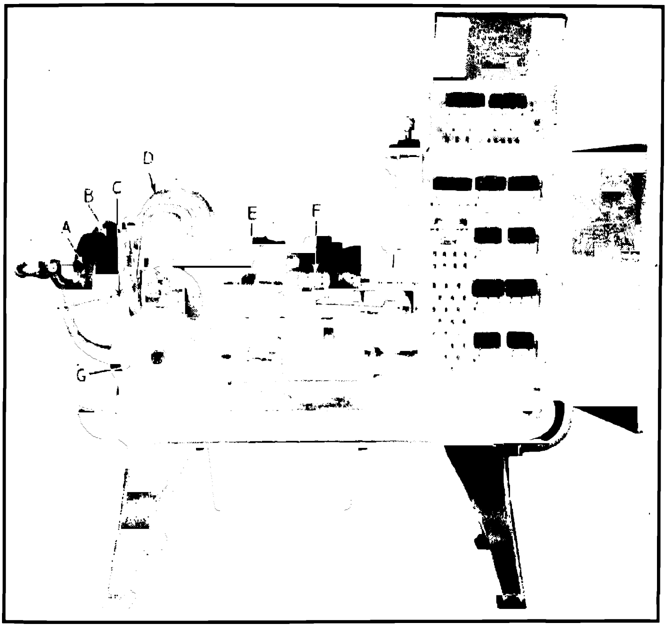


FIG. 15C. A Longitudinal Vertical Section through the Gorton Single-Spindle Automatic Screw Machine Tool Head and Headstock.

The guide bushing for accurately locating the work with respect to the tools is shown at the extreme left at the tool point, while the collet for driving the work is shown at the left end of the headstock.

In the **single-spindle automatic screw machine**, Fig. 16, the turret carrying the tools is a sliding drum *D* having five holes in the end opposing the work spindle. As the turret indexes, the various tools in the turret are brought successively in line with the work spindle. Front and rear cross slides also are provided. These machines are made in various sizes having capacities up to $7\frac{3}{4}$-in.-diam. bar stock. The motorized machines have one motor to drive the spindle and another to drive the feed mechanism and coolant pump.

The camshaft extends the whole length of the machine just back of the spindle and turret. Various drums carrying cams are located on the shaft back of the mechanism they are to operate. The two working cams on the drum *F* which control the cross slides by bell cranks have a fixed angle, but are adjustable around the periphery of the drum so as to bring each cross-slide tool into play in proper relation to the working tool in the turret. Strip cams *A* on the regulating wheel may be adjusted in and out to drive the camshaft at any speed and thereby furnish the desired feed of each individual tool.



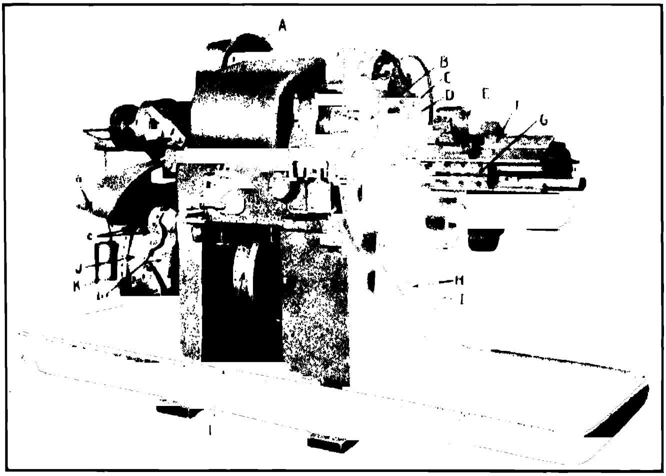
A, strip cams to regulate tool feed; *B*, trip pins for fast-slow feed clutch; *C*, segment gear to raise or lower feed roll to change tool feed; *D*, camshaft motor; *E*, stock feed segment; *F*, cross-slide feed drum; *G*, tool feed disk.

FIG. 16. A Rear View of the 7/8-in.-diam.-Capacity Single-Spindle Model A Cleveland Automatic Screw Machine.

The electric control box for automatically changing the speeds of the driving motor is shown. Sixteen spindle speeds from 55 to 550 are available.

A drum on the left end of the camshaft has thirteen annular grooves which carry the trip dogs. The first three grooves carry trip dogs which start, stop, and reverse, respectively, the spindle. The next two engage clutches for a high- or low-speed series; the last eight control the motor to provide any one of eight spindle speeds for each of the high- and low-speed series.

In the Gridley **single-spindle automatic screw machine,** Fig. 17, the spindle *B*, through which the bar stock is fed, is rotated by gears from a drive pulley *A*. The various end-cutting tools are held on the turret *G*, which has a rotating motion only as it is indexed. The tools are mounted on slides *F* on the several faces of the turret, and are withdrawn or fed against the work by a long shaft extending to the main cam drum *J* on which are mounted the cams for sliding the turret tools, opening and closing the collets, and feeding in the bar stock. The central or operating drum carries trip dogs for indexing the turret, changing spindle speeds by shifting a clutch, and speeding the camshaft for idle movement. The front cross slide receives its motion through a lever from the adjustable cam on the right face of the cross-slide cam disk *I*. The cutoff arm is operated by a cam on the left face of this disk. Change gears are provided for a wide range of speeds and feeds.



Courtesy National Acme Co.

A, drive pulley; *B*, spindle; *C*, cut-off slide; *D*, forming slide; *E*, toolholder; *F*, tool slide; *G*, turret; *H*, main camshaft; *I*, cross-slide cam disk; *J*, main cam drum; *K*, stock feed weight; *L*, center cam drum.

FIG. 17. The Gridley Single-Spindle Automatic Machine Model L Arranged for Bar Work.

This machine is made in four sizes for bar stock up to $2\frac{1}{4}$, $3\frac{1}{4}$, $4\frac{1}{4}$, and 5 in. diam. The main cam drum carries three sets of cams: (*a*) the stock feed cam, (*b*) the collet opening and closing cams, and (*c*) locating holes for turret slide cams.

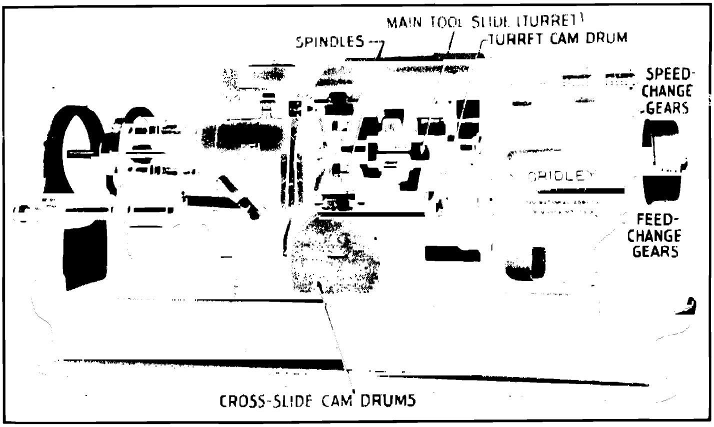
The Cleveland and Gridley single-spindle machines may be adapted conveniently to chucking work, in which case many of the available automatic features, such as bar-stock feed, are not needed.

Multiple-Spindle Automatic Machines

Multiple-spindle automatic screw machines are made having 4, 5, 6, or 8 spindles. All bars of stock are machined simultaneously.

These machines are provided with a spindle carrier, Fig. 19, in which a work spindle, carrying a bar of stock, is opposite each tool position of the head so that all sets of tools are working simultaneously, rather than being brought into play successively. The spindle carrier or work head carrying all bars of stock is indexed after each series of cuts so that each bar is, in turn, brought before each set of tools. A finished part is cut off for each indexing, and the total time for each piece is equal to the time required to perform the longest single operation.

The **Gridley 4-spindle automatic** screw machine, Fig. 18, has end-cutting tools rigidly attached to the corners of the square main toolslide (turret) which is fed against the work by helical cams attached to the turret-cam drum below on the main camshaft. The camshaft extends the full length of the machine below the spindles. The main toolslide is fed against a positive stop to insure the accurate depth of cut of each tool.



Courtesy National Acme Co.

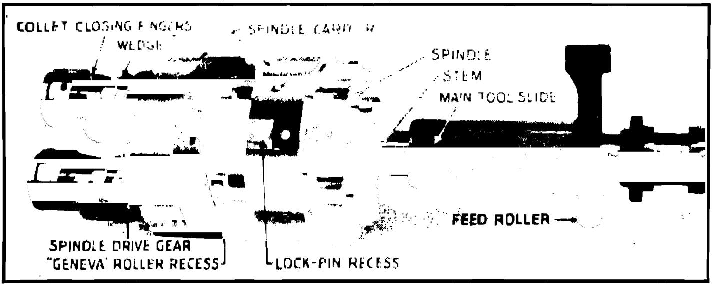
FIG. 18. The Gridley 4-Spindle Automatic Screw Machine Model GA.

This machine is made for bar-stock capacities of $1\frac{3}{8}$, $1\frac{5}{8}$, $2\frac{5}{8}$, $3\frac{5}{16}$, and $3\frac{1}{2}$ in. diam.

Threading or tapping may be done in either the second or third work position, or both. There are four independently cam-operated cross slides, one for each spindle, for forming, shaving, knurling, thread rolling and cutoff tools.

There are two drums, each keyed to a transverse or cross shaft, directly underneath each bottom cross slide. Each drum has two sets of cams. The two bottom cross slides are operated from one cam on each drum directly to a roller on the bottom of the slide. The other cam on each drum operates the two upper slides through an independent lever.

The speeds of the two camshafts, which are connected by spiral bevel gears, are variable to accommodate the cutting and noncutting periods of the cycle. Bar feed occurs between the lower two spindles during indexing. A disappearing stop rises to stop the stock until the collet is closed. This is a single-pulley-drive machine. Spindle speeds and tool feeds receive their power from this common source. The frame and pan are of a box form, with a heavy top bracket to tie the gear section rigidly to the spindle frame.



Courtesy National Acme Co.

Fig. 19. The Spindle Carrier of the Model GA Gridley Automatic.

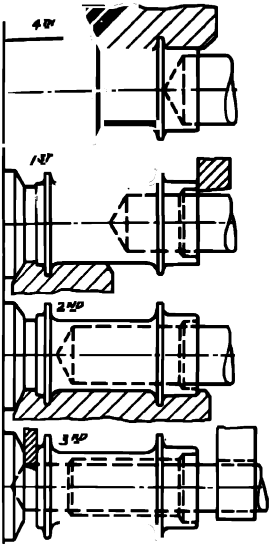
This shows the four collet and feed tubes arranged in the carrier. The steel stem is integral with the spindle carrier and is ground at the same setting as the carrier-bearing surface. The gear on the right end of the stem runs freely for driving high-speed drilling attachments.

An arrangement of the four spindles of the carrier is shown in Fig. 19. The recesses for the roller to provide the Geneva motion for indexing the radial carrier and bar reel are shown on the right-hand face of the left bearing. Also see Fig. 22. The main toolslide is mounted on the spindle-carrier stem with bronze bushings.

Typical examples of work done on the Gridley 4-spindle machine are shown and described in Figs. 20 and 21.

The **Greenlee 4-spindle automatic** screw machine, Fig. 23, has a central toolslide controlled through rack and intermittent gearing instead of the usual drum cams. Adjustable dogs control the feeding length of the slide. The cross-forming slides, one for each spindle, are controlled independently by interchangeable cams. The cams can be changed quickly for different setups, and those of the four slides are interchangeable.

The collet-closing wedges and stock-feeding rings on the end of the spindle are shown in Fig. 22 in relation to the operating drum and



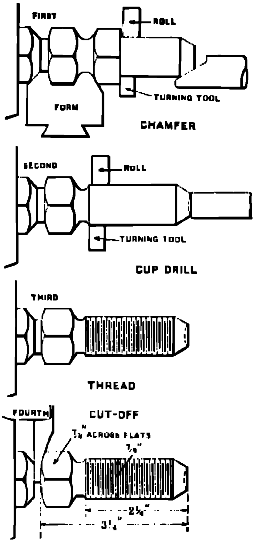


FIG. 20. Machining a Hub Shell for a Bicycle Wheel $2\frac{1}{16}$-in. diam. by $3\frac{5}{32}$ in. Long in a $3\frac{5}{16}$-in. Model GA Gridley 4-Spindle Automatic Screw Machine.

A bar $2\frac{3}{32}$ in. diam. of Supercut steel is rotated at 334 rpm, or 183 fpm. The machining time is 41 sec each, or a gross production of 88 per hr. The operations with high speed steel tools are as follows:

Fourth Position: Rough-form front half with circular form tool, feed 0.0019 in.; drill with feed of 0.0075 in.

First Position: Rough-form rear half with circular form tool, feed 0.0019 in.; face end; drill medium-sized hole half depth, oilhole drill, feed 0.0075 in.

Second Position: Finish-form all over with circular form tool; feed 0.0013 in.; finish-drill medium-sized hole with oilhole drill, feed 0.0075 in.

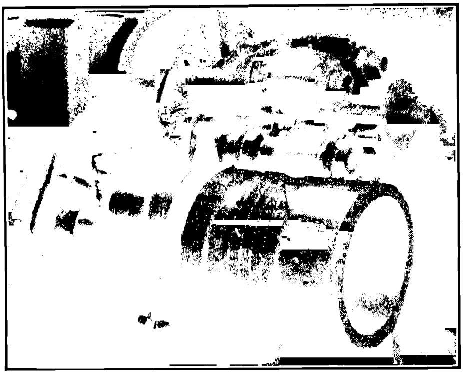
Third Position: Drill small hole to depth with oilhole drill, feed 0.0075 in., and cut off with feed of 0.0019 in., and strip work from drill.

FIG. 21. Machining a Set Screw of SAE X 1315 Steel from ⅞-in.-sq. Stock in a Gridley 1¼-in.-Capacity, 4-Spindle, Automatic Screw Machine.

The operations are indicated.

cams. On the lower left is seen the double-end indexing arm, the roller of which engages the radial slots on the end of the spindle carrier and provides the **Geneva motion** in accelerating and decelerating the spindle carriage during the indexing. A thin cam at the lower left controls the lock-bolt arm for unlocking and locking the spindle carriage before and after indexing. The gearbox is built as a unit and is attached to the end of the frame. It contains the mechanism controlling the spindle speed and feed changes, together with the high- and low-speed clutches, safety clutch, and lubricant and coolant pumps.

Tooling equipment features on the Greenlee include threading tools, and accelerated reaming in either or both the third and fourth positions and high-speed drilling attachment for any or all positions. Turning, drilling, boring, skiving, shaving, and knurling attachments, and toolholders for the varied assortment of operations are carried as stock equipment. Additional auxiliary toolslides can be mounted on the top of the spindle carrier housing for performing operations at either or both the second and third spindle positions. End-working tools can be used in all spindle positions.



Courtesy Greenlee Brothers and Co.

FIG. 22. Rear View of the Spindle End of the Greenlee 4-Spindle Automatic Showing the Stock Feed and Collet Operating Cam Drum.

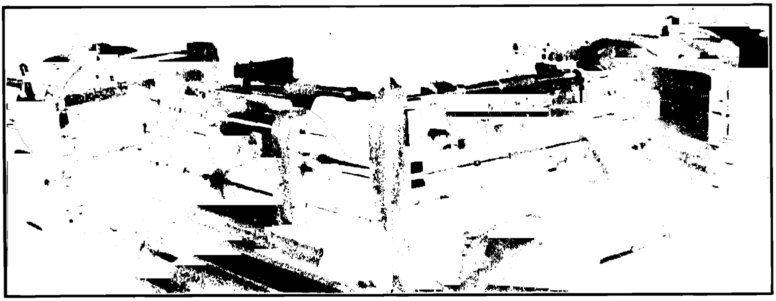
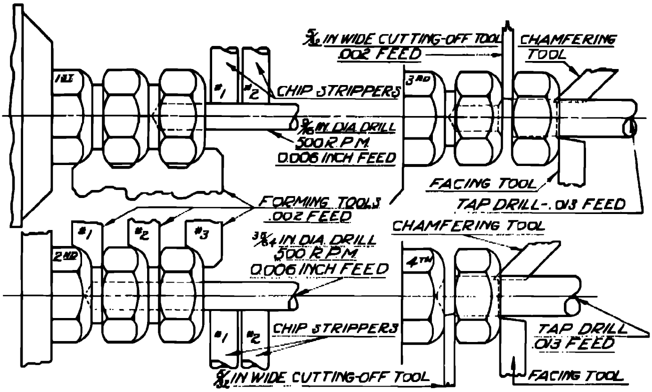


FIG. 23. A Setup for Making Disk Wheel Nuts for Automobiles in the Greenlee 4-Spindle Automatic Machine.

The relation of the four cross slides and the central toolslide with respect to the four spindles is indicated. The first spindle position is below at the left, the second above at the left, the third above at the right, and the fourth below at the right.

Figure 23 shows the tooling, front at left and rear at right, of a typical setup on the Greenlee machine. Hexagonal bar stock is fed out far enough in the first turret position at the lower left for the blanking of two nuts on each bar. One nut blank is cut off in the third and one in the fourth position, making two blanks at each indexing of the machine.

A line diagram of a similar setup for making disk-wheel nut blanks on a 2¼-in. 4-spindle Cone automatic is shown in Fig. 24, in which the tool sizes and speeds and feeds are given. In the **5-spindle automatic** for small work, Fig. 25, the end toolslides and cross slides are operated independently by bell-crank levers running over disk cams located, respectively, on the camshafts at the right end of the bed and



Courtesy J. C. Austerberry's Sons.

FIG. 24. The Tooling Setup in a 2¼-in. 4-Spindle Cone Automatic for Producing Disk Wheel Nuts for Automobiles at the Rate of Two Nuts for Each Indexing.

The spindle speed is 309 rpm, giving a cutting speed of 138 fpm. The time is 19½ sec for two pieces, giving a gross production of 368 per hr.

Two high speed steel chip strippers and a high-speed drilling attachment are used with the drills in the first and second spindle positions. Forming tools 1 and 2 at second position are set in holders on a 2-deg angle; no side relief is required.

underneath. Adjustments with graduations on the bell-crank levers permit control of travel for each tool. It is a single-pulley or motor-drive machine with change gears to obtain any desired speed of a large ring gear with internal teeth which in turn drives a gear on each spindle. This is a very fast machine for small work up to ½ in. round, 7/16 in. hexagonal, or 3/8 in. sq. by 3 in. long, and is able to turn out quite complicated parts at the rate of 1 or 2 sec each or less. The regular machine indexes in ½ sec with a spindle speed of 2,400 rpm. The high-speed machine with forced feed lubrication indexes in 2/5 sec and with a spindle speed of 3,643 rpm. These machines have a full range of speeds and feeds for either brass or steel.

The machine can be equipped with a fifth cross slide and various attachments for burring, countersinking, and slotting the cutoff end of the work. When threads are cut, the work spindle is not stopped or reversed, but the spindle carrying the die or tap is revolved in the same direction as the work spindle at ¾ the speed when running the

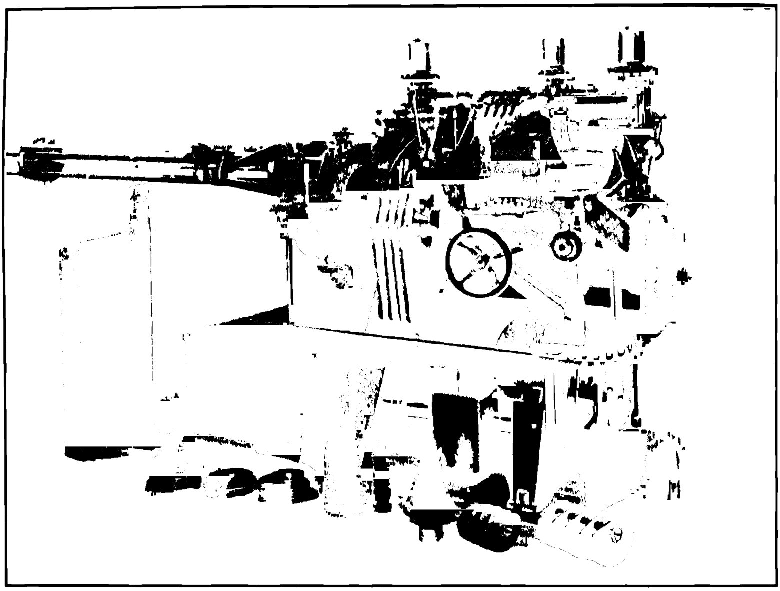


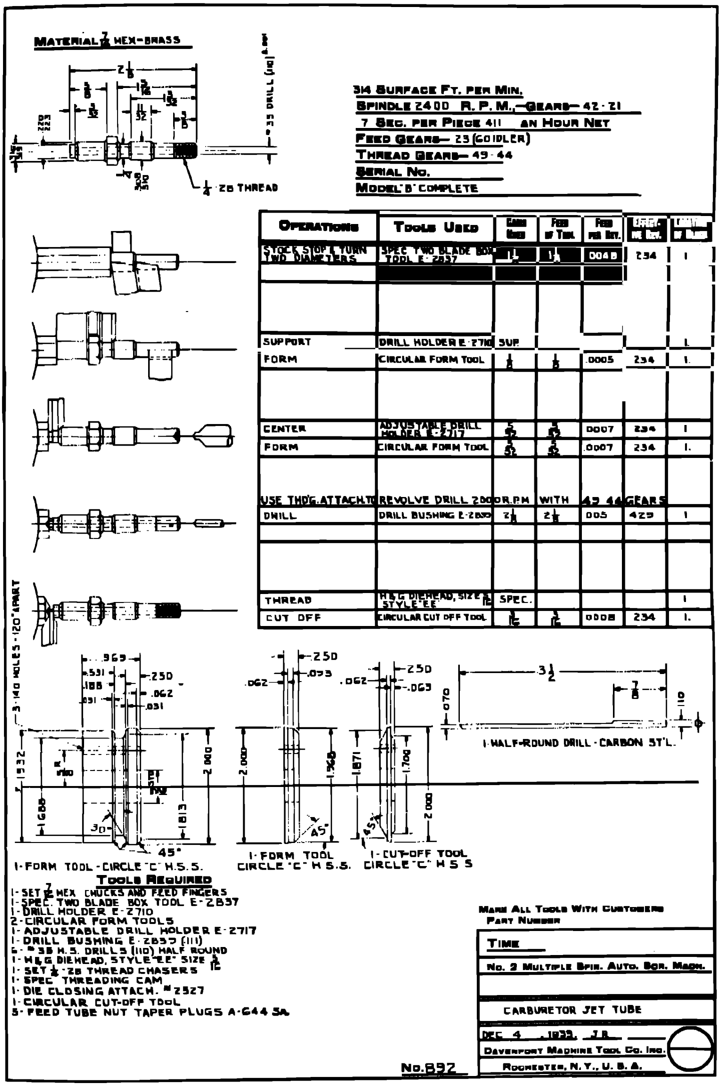
Fig. 25. The Davenport Model B 5-Spindle Automatic Screw Machine Arranged for Motor Drive with the Motor Located underneath the Machine.

The arrangement of the four cams on a cam carrier for the four cross slides, and of the five cams on their cam carriers for the five end toolslides is shown together with extra sets of cams and speed- and feed-change gears on the floor. Three central oilers are located above the machine, and cutting-fluid pipes are located in position for the various work spindles.

die on and $\frac{3}{2}$ to back it off. An example of work done on the 5-spindle Davenport is shown in Fig. 26. Five- and **6-spindle automatic** screw machines are made quite similar to the 4-spindle Gridley. With 6 or more spindles, production may be increased considerably by subdividing the longer operations, such as deep drilling, long turning, and forming. On simple work, two or three pieces can be handled per index by cutting off in two or three positions.

A typical job in making a cap screw of cold-rolled SAE 1020 steel on the 6-spindle machine is as follows:

Spindle	*Cross Slides*	*Toolslide (Turret)*
1.		Feed stock to stop.
2.	Rough-form head and ¼ in. on body.	Rough-turn halfway.
3.	Finish-form head and ¼ in. on body.	Rough-turn remainder.
4.		Accelerate finish-turn entire length of body
5.	Break down for cutoff.	Thread with self-opening die.
6.	Cutoff.	Support with bushing.


MATERIAL 7/16 HEX-BRASS
2 1/16
#35 DRILL (110) 4 DEEP
1/4-28 THREAD
1-FORM TOOL-CIRCLE "C" H.S.S.
1-FORM TOOL CIRCLE "C" H.S.S.
1-CUT-OFF TOOL CIRCLE "C" H S S
1-HALF-ROUND DRILL-CARBON ST'L.
3-1/4 HOLES-120° APART
45°
30°
No. 892

314 SURFACE FT. PER MIN.
SPINDLE 2400 R.P.M.—GEARS—42-21
7 SEC. PER PIECE 411 AN HOUR NET
FEED GEARS—23 (GOIDLER)
THREAD GEARS—49-44
SERIAL NO.
MODEL "B" COMPLETE

OPERATIONS	TOOLS USED	[illegible]	FEED OF TOOL	FEED PER REV.	EFFECTIVE REV.	[illegible]
STOCK STOP & TURN TWO DIAMETERS	SPEC. TWO BLADE BOX TOOL E-2837	1 1/4	1 1/4	.0048	234	1
SUPPORT	DRILL HOLDER E-2710	SUP.				1
FORM	CIRCULAR FORM TOOL	1/8	1/8	.0005	234	1.
CENTER	ADJUSTABLE DRILL HOLDER E-2717	5/32	5/32	.0007	234	1
FORM	CIRCULAR FORM TOOL	5/32	5/32	.0007	234	1.
USE THD'G. ATTACH. TO	REVOLVE DRILL 2000	R.P.M.	WITH	49 44	GEARS	
DRILL	DRILL BUSHING E-2839	2 1/8	2 1/8	.005	429	1
THREAD	H & G DIEHEAD, SIZE 5/16 STYLE "EE"	SPEC.				1
CUT OFF	CIRCULAR CUT OFF TOOL	1/16	1/16	.0008	234	1.

TOOLS REQUIRED

1-SET 7/16 HEX CHUCKS AND FEED FINGERS
1-SPEC. TWO BLADE BOX TOOL E-2837
1-DRILL HOLDER E-2710
2-CIRCULAR FORM TOOLS
1-ADJUSTABLE DRILL HOLDER E-2717
1-DRILL BUSHING E-2839 (111)
6-#35 H.S. DRILLS (110) HALF ROUND
1-H & G DIEHEAD, STYLE "EE" SIZE 5/16
1-SET 1/4-28 THREAD CHASERS
1-SPEC. THREADING CAM
1-DIE CLOSING ATTACH. #2527
1-CIRCULAR CUT-OFF TOOL
5-FEED TUBE NUT TAPER PLUGS A-644 5A

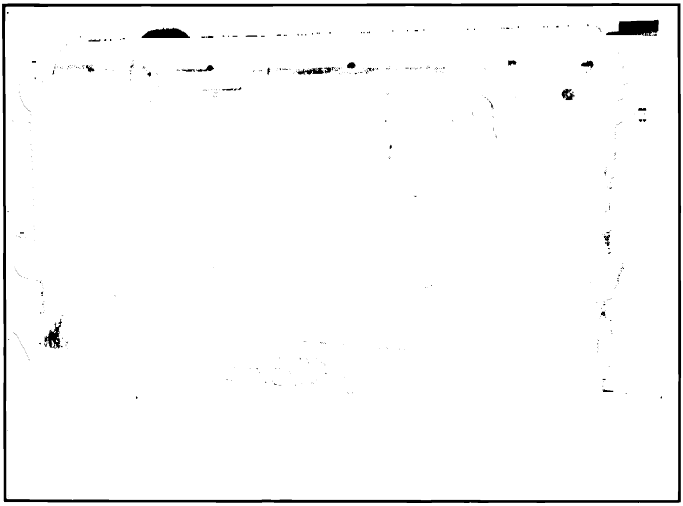
MARK ALL TOOLS WITH CUSTOMERS PART NUMBER

TIME
No. 2 MULTIPLE SPIN. AUTO. SCR. MACH.
CARBURETOR JET TUBE
DEC 4 , 1933, J.R.
DAVENPORT MACHINE TOOL CO. INC.
ROCHESTER, N.Y., U. S. A.

FIG. 26. The Tools and Operations for Machining the Carburetor Jet Tube Shown in the Drawing from Free-Cutting Brass Rod on a 5-Spindle Davenport No. 2 Automatic Screw Machine at the Rate of 411 Pieces per hr.

Carbon-steel drills are used for the drilling instead of high speed steel, as they seem to be about as efficient as high speed steel. "Circle C" superhigh speed steel is used for forming the outside of the brass rod. This is considered best by the company, except where cemented carbide is used. Paraffin oil was used as a cutting fluid.

An 8-spindle automatic screw machine is illustrated in Fig. 27. The spindle carrier indexes 45 deg each time. The cutoff time is shortened, so that the cutoff and bar feed occur during the normal operation of the other tools. Cutoff and bar feed occur at the top front, station 1, for the 8-spindle setup, and at the bottom rear, station 5, for the twin-four setup. The twin-four setup has two identical sets of tools such as for two independent 4-spindle machines. The bar stock may be fed the length of the piece at stations 1 and 5, or it may be fed twice the length plus the cutoff length, in which case the first set of tools machines a piece from the first half, and the second set of tools, placed forward, machines a piece from the second half.



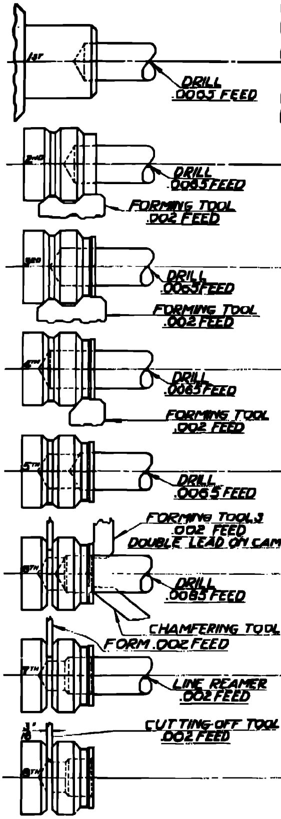
Courtesy Cone Automatic Machine Co.

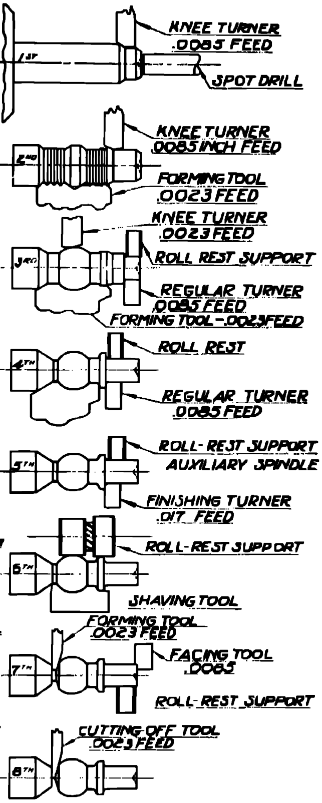
FIG. 27. The Cone 1¼-in.-Capacity 8-Spindle Automatic Screw Machine.

The eight spindles may be used in setting up for eight consecutive operations for complicated jobs or as a twin-four machine for high production of simple jobs.

An 8-spindle operation illustrating deep drilling in successive steps is given in Fig. 28. Figure 29 shows accurate turning and forming being done in the Cone 8-spindle machine.

The Cone Automatic Machine Co. also manufactures 4- and 6-spindle vertical automatics, in which the spindles are horizontal but mounted vertically one above the other. These machines are used principally for cutting off work such as piston pins. Piston pins can be cut off from a 1-in.-diam. solid shaft of SAE 1020 steel at the rate





Courtesy Cone Automatic Machine Co. *Courtesy J. C. Austerberry's Sons.*

Fig. 28. Fig. 29.

Fig. 28. A Deep Drilling Job Being Performed on a 1⅞-in. Capacity 8-Spindle Cone Automatic Screw Machine.

The material for a speedometer driving gear is a 0.35 per cent carbon steel. The spindle speed is 206 rpm, giving a cutting speed of 95 fpm. The time per piece is 17 sec.

Fig. 29. A Complicated Forming Job Being Performed on a 1¼-in. Capacity 8-Spindle Cone Automatic Screw Machine.

The material of the steering-arm ball is 1$\frac{5}{32}$-in. hot-rolled round steel G.M.C. No. 3135-A. The spindle speed is 316 rpm, giving a cutting speed of 85 fpm. The machining time per piece is 11.0 sec, giving a gross production of 310 pieces per hr.

of 1,800 per hr on the 4-spindle machine. These machines are primarily for cutting off on all spindles, but they are so arranged that light forming, chamfering, and drilling may be done.

Stock magazines are often used on automatic screw machines to hold an accumulation of stock to be presented to the collets for machining. Some hold long bars; others hold short shafts, forgings, castings, or parts which have been machined from bars in a previous operation and require a second on the cutoff end. The work is usually forced into the open collet through the spindle, or from the front against a coil spring or other mechanical device which ejects it when the collet is opened after machining. Sometimes positive mechanical knockout devices are used.

There are several types of magazines. All are designed to enable one operator to care for more than one machine at a time by keeping the magazines filled with rough stock, which is fed automatically to the spindle as required. The **rod magazine** is used to replenish long bars in the spindle of the single-spindle automatic. A **vertical hopper** is used for holding short shafts to be fed through the spindle or to be inserted into the collet from the front. The **chute,** of either the tilting type or stationary type, Fig. 9, is used so that parts stored in it are fed by gravity to a loader which carries them to the spindle. The **rotary spring-clip magazine** consists of a drum or disk mounted on a special shaft which carries on its periphery a series of spring clamps which hold the work until it is gripped by a transferring tool in the turret and transported to the chuck for the first operation. The operator keeps the spring clips filled with work, such as bolts and piston pins, requiring a second operation. The drum is indexed to bring the work opposite the loader.

The **rotary magazine** consists of a drum arranged to hold many parts in its periphery. It operates similarly to the rotary spring-clip magazine. In the rotary tilting magazine, the part to be inserted in the spindle is moved to the work loader. After the part is removed from the magazine, the latter swings upward out of the way of the working tool. The **rotary chain conveyor** also is employed to carry a number of parts which are laid in recesses on the top of the chain. The chain advances, carrying the work to the loader at the proper time.

The **centerboard hopper** is placed on the top of the machine. It is used for parts having heads. The centerboard oscillates vertically in the hopper filled with parts, to cause the parts to fall into an inclined chute which leads the work by gravity to the spindle loader. The chute supports the parts under the head so that they are all presented to the loader in the same position, Fig. X-31.

Single- versus Multiple-Spindle Automatic Screw Machines

Cost and accuracy of the finished part are the two chief elements which enter into consideration as to whether a single- or multiple-spindle machine should be used for a certain job. The element of **cost** includes setup time, tool cost, and operating cost. Operating cost includes **direct material** of which the product is made, **direct labor,** and **overhead.** The overhead includes cost of floor space, investment in machines, taxes, depreciation, upkeep, cost of tools, and power input. These items are usually larger for the multiple-spindle than for the single-spindle machine. Costs are usually reduced to an hourly basis of operation.

The **cost** of the tooling equipment and setting-up time for producing a part is of great importance and should be kept to a minimum, particularly when the quantity involved is small. Parts in small quantities can be made cheaper on a hand-operated screw machine or a single-spindle automatic than on a multiple-spindle machine because of the higher cost, special tools required, and the greater time necessary to set up and adjust them in the more complicated machines. These costs are of less importance when a very large number of parts is produced, as the high tooling cost required to produce a part in the shortest time becomes almost negligible when prorated over a great quantity. **Quantity** of production is in itself no conclusive criterion to indicate a single- or multiple-spindle automatic machine. Short runs involving **small quantities** call for a machine which can be set up quickly with inexpensive tools. **Large quantities,** requiring four days or more, indicate the multiple-spindle type of machine.

The **material cost** of each part will be the same whether machines having one or more spindles are used, as long as the same material is used. The spindle carrying the bar stock in the single-spindle machine may be driven directly by a belt on a pulley, whereas the several spindles of a multiple-spindle machine are driven by gears from a central spindle. The direct belt drive permits greater rotating speeds, and, therefore, it is good practice in many cases to substitute brass for the usual cold-finished steel screwstock, in order to take advantage of the much higher cutting speeds permissible with free-cutting but more expensive brass. For small work of either steel or brass, the proper cutting speeds are more easily obtained in the single-spindle machine.

Direct-**labor cost** is a poor basis for machine selection because of its insignificant value when reduced to a single piece. In any case, the operator could attend several machines, and the greater production in pieces of the multiple-spindle group might require more labor in attending the machines which are complicated or require inspection of a greater percentage of parts.

Multiple-spindle machines, in general, are superior as far as the **rate of production** is concerned, as all tools are operating simultaneously and the cutting time for each station is the time of the longest single cut. Thus, for long turning or deep drilling, or when there is considerable material to be removed by forming tools, etc., the time can be reduced to one-half or one-third by doing part at one position and the balance at another. In drilling a hole 3 in. deep in a 4-spindle machine, the hole could be drilled to 1-in. depth at the first position of the spindle, to 2 in. at the second, and to 3 in. at the third, each of the three drills cutting 1 in. and then being withdrawn to clean out the chips. The total drilling time is, therefore, the time required to drill 1 in. This process also prolongs the life of the drills.

In the single-spindle machine, the rotating spindle is stationary, while the tools held in the turret are **indexed** to be brought successively into action against the work. The weight of the turret and tools is little, so the indexing is accomplished with great rapidity. If the turret has six faces or positions each with a tool, then for each part produced there will be six indexings. In the multiple-spindle machine, the tools do not index, but the spindle carrier and the bar-stock reel do. This involves a great weight to accelerate and retard, so the motion is somewhat slower. A part is completed, however, at each indexing.

The single-spindle machine is credited with more **accurate** work than the multiple. There are many more moving parts in the multiple-spindle machine, each fit admitting some error. It is difficult to secure accurate index-spacing in the work head of the multiple-spindle machine because of the mechanical difficulties of constructing a machine having several parallel work-spindles which are equally spaced and equidistant from the axis of the spindle carrier.

An operator of a large screw product company has summarized the characteristics of single-spindle and multiple-spindle machines of various types as viewed from the operating and setting-up standpoint, as follows:

1. The Brown and Sharpe single-spindle automatic has the highest spindle speeds available and produces very accurate parts. The six turret positions are an advantage. The cams and tools are relatively expensive.

2. The Cleveland single-spindle automatic is good for short runs by means of standard camming and changing dogs. Tooling is relatively inexpensive. Setup time is short. Spindle speeds are not high enough for brasswork.

3. Four-spindle machines, such as the Acme, Cone, Greenlee, and Gridley, have relatively low spindle speeds. They are rugged and good for heavy cuts. Fairly quick setup time for simple jobs. Especially desirable for jobs where the cut can be split between several positions, or for multiple setups for simple work.

4. Davenport automatic with 5 spindles. Extremely fast for brasswork, although spindle speed is lower than that of the Brown and Sharpe. Rather costly to tool, but has quick setup time for repeat jobs. Will not stand heavy cuts and so is better for brass- than for steelwork. Quick indexing time is an advantage.

5. Other multiple-spindle machines with more than 4 spindles should be selected on a basis of size, power, and convenience. For use particularly on extremely high production, complicated work, or where a great deal of metal is to be removed.

If a firm is purchasing a small number of machines for making its own parts, the selection is an entirely different matter from that for a shop engaged in the manufacture of screw products. For running **medium-sized quantities,** it is believed that, in the long run, a small battery of single-spindle machines will be cheaper than multiple-spindle machines. For the same number of items to be run the investment in collets and fingers and in tools necessary on the multiple-spindle machines would be a great deal larger than that for the single-spindle machines. This high investment and greater maintenance cost, combined with the tool items, would more than offset the lowered cost in producing on multiple-spindle machines.

Speeds and Feeds for Automatic Screw Machines

Values for speeds and feeds for automatic screw-machine work can serve, at best, only as a general guide for starting. They must be selected to suit the type and size of machines, the depth of cut and feed, the material and size of the work, and the number and types of tools to be used. Subsequent modifications should be made based upon specific results and general conditions. Cutting speeds for a variety of materials and processes and for screw machines are given above.

QUESTIONS

1. What is the principal difference between an automatic lathe and an automatic screw machine?
2. Why is the automatic screw machine called "automatic" and the automatic lathe called "semiautomatic"?
3. Explain the difference between an automatic toolslide lathe and an automatic turret lathe.
4. What are some of the special-purpose semiautomatic lathes?
5. Explain the difference in indexing in the single-spindle automatic screw machine and the multiple-spindle machine.
6. What is the Geneva motion? Explain its advantages.
7. How are multiple-spindle automatic machines superior to the single-spindle machines when considerable metal is to be removed, as in deep drilling or long turning?
8. What types of cutting fluids are best for automatic screw-machine work?
9. Explain the difference in principle of operation of the single-spindle Brown and Sharpe automatic screw machine and the Gorton Swiss type.
10. Explain why the 5-spindle Davenport automatic has greater productive capacity than the Brown and Sharpe automatic with a 6-position turret.

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CHAPTER XIII

BROACHING

DEFINITION

Broaching consists of machining surfaces by drawing or pushing entirely past the surface one or more cutters, called broaches, having a series of cutting teeth. The teeth of the broach increase in height from one end to the other. The first teeth are low or short so as to permit the small end of the broach to enter the hole in internal broaching, or pass over the surface in external broaching before engaging the surface. The first and intermediate teeth remove most of the metal; the last few teeth finish the hole or surface to size.

APPLICATION OF BROACHING

Many jobs formerly considered practical only for milling are being broached to greater accuracy at a higher rate of production. One advantage in broaching is that the cutting force of the broach often serves to clamp the part. Many broaching operations are completed in the time ordinarily taken to clamp the piece. Broaching is superior to reaming because the broach will hold its size for a much longer period of time, thus insuring greater accuracy. Other advantages are the good finish, great speed of production, interchangeability of the work, and adaptability of the broach to produce irregularly shaped holes or forms. The broach will machine many more pieces per grind than any other type of cutter, owing to the great number of teeth. Each individual tooth works for only a short period of time per piece as the total depth of cut is proportioned over the total number of teeth.

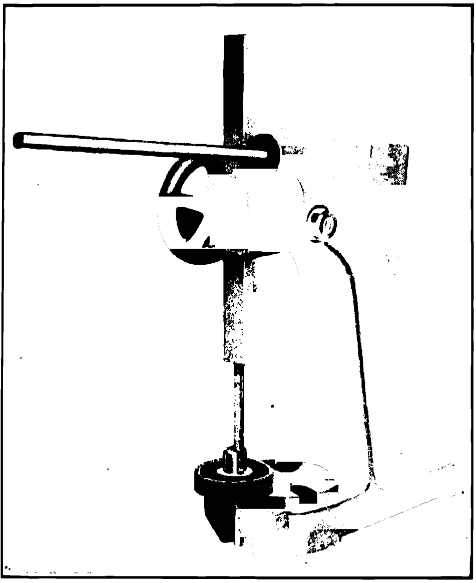
BROACHING MACHINES

Broaching machines may be **classified** as:

1. Manually or power operated.
2. Horizontal or vertical.
3. Pull, push, or continuous.
4. Single or multiple pull head.
5. Moving or stationary cutter.
6. Mechanical or hydraulic drive.

Manually operated machines, Fig. 1*A*, are sometimes used for broaching in job or repair shops for light work. The **power-driven** machines are usually quick acting with a ram, or drawbar to which the broach is attached in the pull-type machines, driven by crank, rack and pinion, screw, or hydraulically.

Push broaching, Fig. 1*A*, is usually performed with short broaches, Fig. 1*B*, on the vertical-type machine. **Pull** or draw broaching is performed on either the horizontal or vertical type of machine. The broach during the cut may be stationary and the work carried past on a chain conveyor, Fig. 3, or on a traveling table.



Courtesy Threadwell Tap and Die Co.

FIG. 1*A*. A Small Bench, Ratchet-Driven Arbor Press of 1 to 40 Pressure Ratio, Used in Cutting a Keyway in a Gear with a Push-Type Keyway Broach.

Horizontal Broaching Machines

In an early horizontal-type broaching machine, a **buttress pulling screw** was used. The lever controlled the belt shifter manually so that the pulling screw could be stopped, started, or reversed at any time. Locking collars were placed on a control shaft at the side of the screw to operate the belt shifter at the limiting ends of the stroke. The motion of the pulling screw was reversed at each end of the stroke. The return stroke was at high speed when the driving belt was transferred onto the reversing pulley which drove the screw nut through planetary gears.

The **horizontal, hydraulic-feed** broaching machine, Fig. 2, is equipped with a motor-driven, variable-displacement pump. A direct-reading **pressure gage** shows the actual pull in pounds. The adjustable **safety valve** may be set to stop the broach travel when the pull exceeds the desired amount. Setting this valve is but a matter of seconds and saves broach breakage. The power efficiency of an Oil-gear broaching machine at full load and full speed is 90 per cent. On loads below maximum capacity, power is used corresponding to the load only.

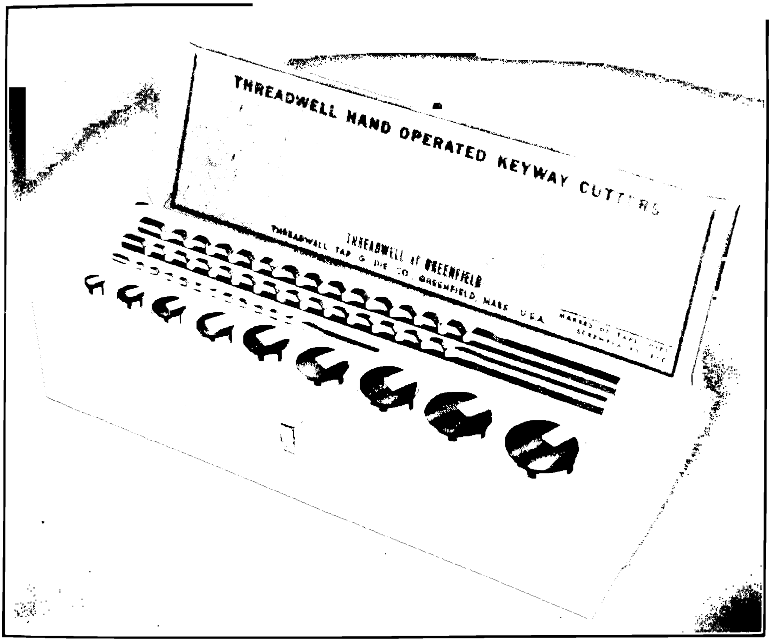
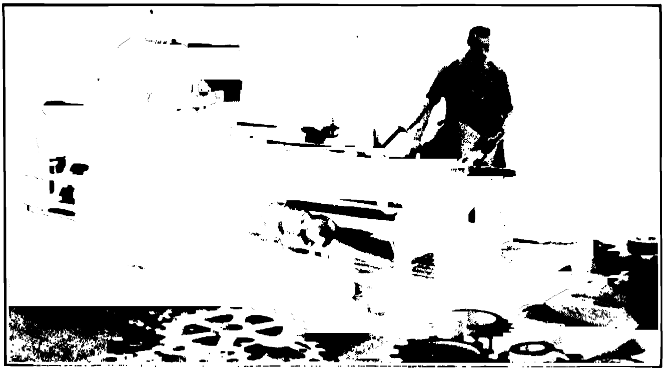

THREADWELL HAND OPERATED KEYWAY CUTTERS
THREADWELL TAP & DIE CO. GREENFIELD, MASS. U.S.A.
THREADWELL OF GREENFIELD

Fig. 1*B*. Three Push Broaches of ⅛, 3/16, and ¼-in. Width and Nine Bushings from ½ to 1½-in. diam. for the Job-Shop Broaching of Keyways in Miscellaneous Parts.

The **control mechanism** is centered in a hand lever and a foot pedal at the operator's station. Either the lever or foot pedal starts or reverses the ram at the end of the stroke. The ram can be stopped at any point in its stroke by the hand lever. By using the foot pedal to start and reverse the ram, both hands of the operator are free to serve the machine and work. **Automatic stops** can be set on the horizontal control bar over the pull head to control the length of the stroke. On the standard machines, the pull head stops at each end of the stroke and must be started again by the operator. By a simple change in the cams, the machine will automatically reverse the travel of the broach at the end of its stroke. The **pull head,** which connects the piston rod to the broach, is adjustable vertically by the small handwheel so that the broach may be centered with the work or broach bushing. When heavy broaches are handled, a **sliding broach support** not shown is attached to the right end of the machine to speed up production by simplifying the handling of the broach and reducing fatigue of the operator. The **chip pan** is seen under the work to catch the chips and cutting fluid and return the latter to the reservoir in the base of the machine. In **duplex machines** having two sets of broaches one operator can load and unload each fixture as the two cutters work alternately, one on the return while the other is pulling.

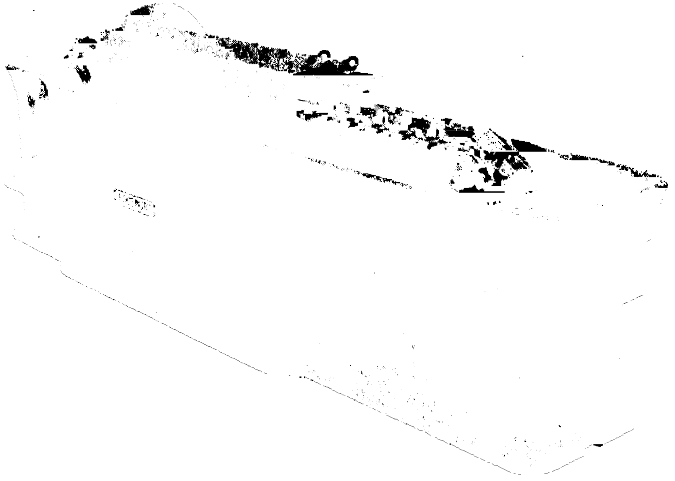


Courtesy The Oilgear Co.

FIG. 2. The Oilgear No. 4 Standard Horizontal Broaching Machine Arranged with Special Cutter Bar and Index Fixture for Broaching Square Holes in Jaw Clutches.

The hole is bored to $4\frac{7}{16}$ in. diam. and broached to $4\frac{1}{4}$ in. sq. in eight draws, two draws for each corner. The three clutches on the box show the part as bored round, flat broached by the cutter in the machine, and corner broached by the cutter on the box, respectively. Production time on broaching machine is 23 min each. It previously required 3.6 hr each when done on a slotter.

The **continuous-type** broaching machine, Fig. 3, consists of a broach mounted horizontally with an endless chain on which are mounted fixtures that carry the work through the cut below the broach. These fixtures in most cases are self-clamping and unclamp automatically at the end of the cut so that the piece drops out and down the chute at the left end. A limit switch bracket is mounted just above the fixtures at the point where the fixtures enter the broach. If the part should be tilted or improperly loaded in the fixture, the switch stops the machine instantly. Any number of fixtures can be mounted on the chain, and the usual limiting factor of production is the ability of the operator to load the pieces in the fixtures as they pass before him. For broaching small parts in large quantities, rotary continuous surface machines are used (*American Machinist,* Jan. 3, 1934, p. 27).



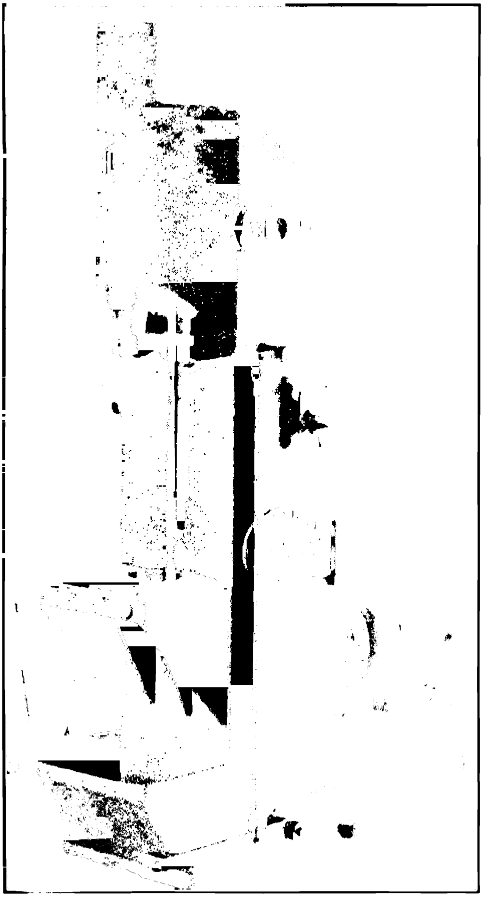
Courtesy Foote-Burt Co.

FIG. 3. A Continuous-Type Surface-Broaching Machine.

The fixtures carrying the work are mounted on the endless chain. The first fixture from the right is empty; the second and third are loaded. The chain is driven at any desirable speed by a motor mounted on the rear left which drives through speed-reduction and change gears.

Vertical Broaching Machines

A small vertical hydraulic-feed press which may be used for push broaching, pressing, assembly pressing, and arbor press work is illustrated in Fig. 4. The ram is normally in the upper position, but is forced downward by stepping on the foot pedal or by the hand lever. Immediately upon the release of either the lever or the foot pedal the ram automatically returns to the top position. The base of the column holds 17 gal of a medium grade of cylinder oil which is pumped at a maximum capacity of 640 psi to the cylinder. Oil is delivered to the full area of the piston for the downward stroke, and on the bottom for the return stroke which is made at approximately 33 per cent increase in speed over the downward stroke. The pump is of the constant-delivery, continuous-flow type, and the ram is controlled by means of a balanced piston valve located just back of the cylinder. A relief valve can be set so that any maximum pressure desired can be obtained. With the pump drive shaft operating at 1,200 rpm the ram operates at 29 fpm down and 38 fpm reverse. Other speeds are obtained by changing the flow control valve.



Courtesy American Broach and Machine Co.

FIG. 4. The Type V-1, 2-Ton Vertical Push-Broaching Press.

This machine is operated by a 3-hp 1,200-rpm motor to a constant-delivery oil pump delivering up to 640 psi max. as read on fan-type pressure gage. Normal working capacity, 2 tons; maximum, 4 tons. Maximum stroke, 14 in.

A crank type of keyseater, designed especially for cutting keyways in the hubs of pulleys, gears, etc., as a job-shop operation, contains a crank gear and crosshead for imparting a vertical reciprocating motion to the saw-type cutter bar, Fig. 5. The cutter is swung in a vertical plane to provide the horizontal feeding movement against the work.

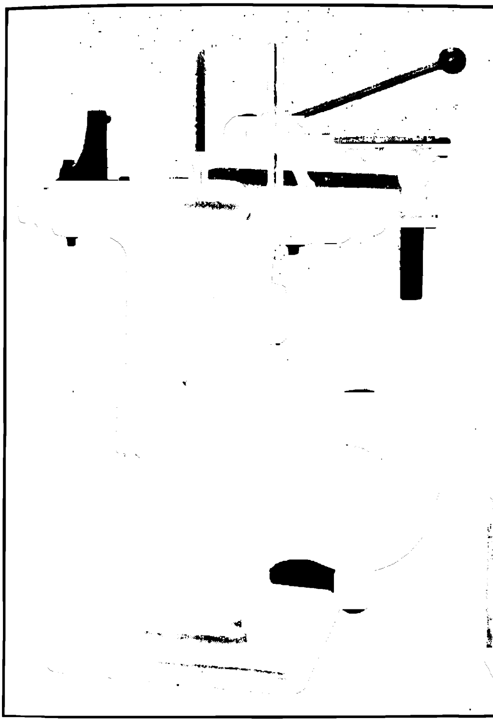


FIG. 5

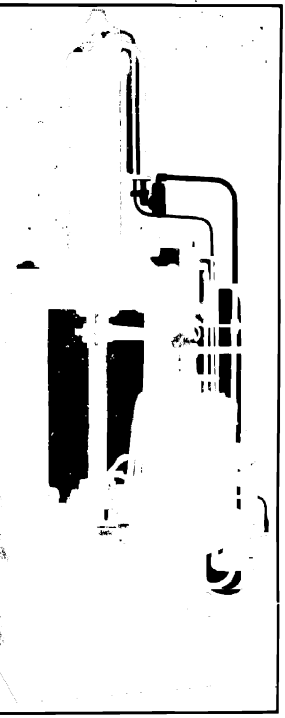


FIG. 6

FIG. 5. The Davis Crank-Type Job-Shop Keyseater. *(Courtesy Davis Keyseater Co.)*

The saw-tooth cutter is forced by hand through the lever against the work on each vertical stroke. The work is supported about the cutter against the adjustable V-shaped holder or by clamps.

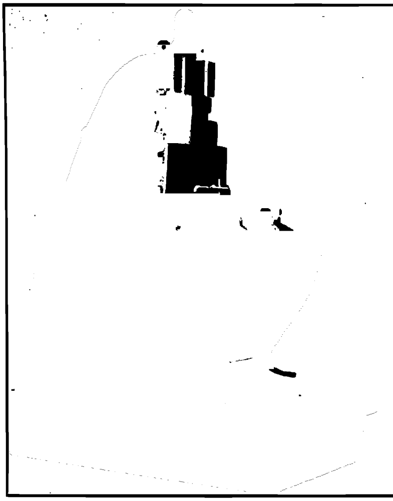
FIG. 6. The Oilgear Company 10-Ton, 2-Column, Vertical Automatic Push-Broaching Press, Equipped with Broaching Tool and Automatic Indexing Fixture for Surface Broaching the Ends of the Spokes of Cast-Steel or Malleable Cast-Iron Wheels.

The press is started by tripping a hand lever at the right, and it completes a cycle of six strokes, broaching one spoke on each stroke, and stopping automatically at the top of the last stroke. The wheel in the fixture is indexed automatically when the broach reaches the top of each stroke. The operating time required to broach a 6-spoke wheel is approximately 95 sec, exclusive of loading and unloading time.

The cutter is backed up by the horizontal arm which also serves to feed it forward at each stroke. Cutters for all sizes of standard keyways are available. The cutters are sharpened by grinding the land.

A **vertical, two-column,** hydraulic-feed, push-broaching machine set up with broach and fixture is shown in Fig. 6. The variable-delivery Oilgear pump, driven by a constant-speed motor, is used to reciprocate the cutter.

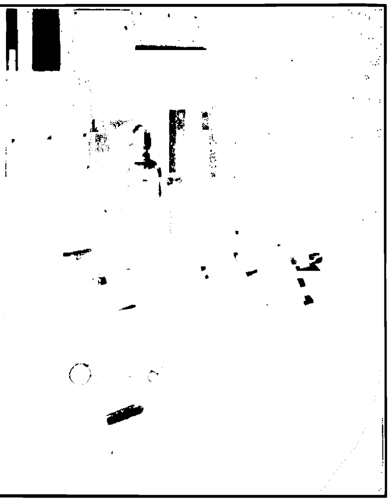
The Foote-Burt **vertical duplex surface-broaching machine,** equipped with cutters and work-holding fixtures, is shown in Fig. 7. A close view of the fixtures and cutters for surface broaching automobile connecting rods is shown in Fig. 8. The machine has two broach slides which counterbalance each other as they are joined together with a helical driving pinion engaging the helical rack on the inner edge of each slide. When one slide is driving down in cutting, the other is automatically returned. The speed of the machine is limited only by the ability of the operator to load and unload the fixtures. The range of cutting speeds averages from 3 to 40 fpm.



Courtesy Foote-Burt Co.

FIG. 7. The No. 3 Vertical Duplex Surface-Broaching Machine Set Up for Broaching the Contact Face and Radius of Connecting Rods and Caps.

The vertically adjustable cam on the left edge of the broach slide is the upper one of two to reverse the travel of the slide by reversing the motor.

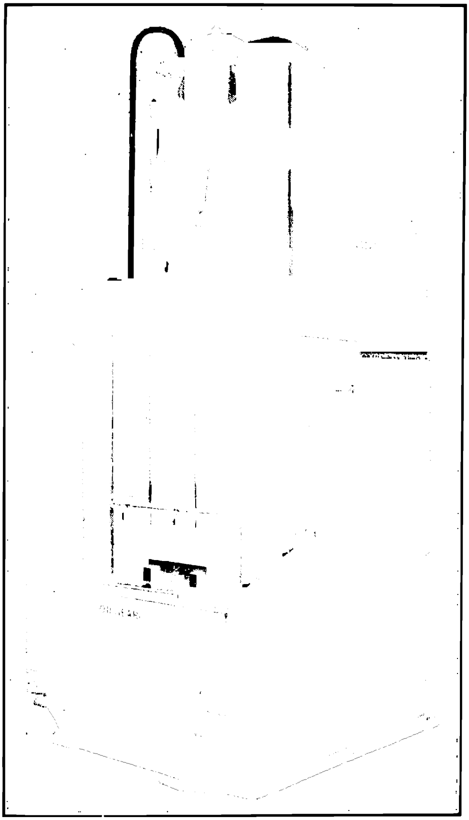


Courtesy Foote-Burt Co.

FIG. 8. A Close-Up of Fixtures and Broaches of Fig. 7.

Bolt bosses on both sides of the connecting rod are being finished in one cut. The two sets of broaches and fixtures are exactly alike. One fixture is swung open while the work in the other fixture is being broached on the downstroke of the cutter slide.

The **vertical broaching machine,** Fig. 9, goes through a complete cycle automatically as follows: The work is placed on the table 30 in. from the floor in fixtures to centralize roughly the work under the broaches. The starting foot pedal is depressed. The broaches, supported at the upper end by the broach-handling cylinder in the upper position, now move down through the work and engage the lower end in mechanically locking pull heads underneath the table. The descending broaches accurately centralize the work. The table is moved



Courtesy The Oilgear Co.

FIG. 9. The Oilgear Cyclematic Vertical Hydraulic-Feed Broaching Machine Fitted with Two Circular Pull Broaches.

The broaches are rigidly secured at both ends while the table on which the work is placed is elevated. Normal pulling capacity is 26,000 lb. The stroke is from 24 to 48 in. The cutting speed ranges from 18 to 32 fpm, and a 20-hp motor is used.

upward by two parallel hydraulic cylinders, one on each side of the table, drawing the work over the stationary broaches. At the top of the stroke, the upper locking sockets disengage the broaches and the table travels on until the work clears the cutter shanks. The broaches are secured at both ends over the critical part of the cut. As soon as the broaches clear the work, an ejector bar moves forward removing the work from the holding fixtures, usually forcing the work into a chute. The worktable descends to the loading position and at the bottom of the stroke disengages the pull heads which hold the low end of the broach. The broach-handling cylinder descends; the sockets engage the broaches and lift them to the starting position so that the lower end is free and well above the loading fixture.

One, two, or three broaching tools can be used simultaneously, permitting rough and finish broaching at the same time, or multiple broaching for very large production. As the work passes upward, the space between each two broach teeth and the walls of the work fills with the cutting fluid which continually floods the upper surface of the work, insuring cooling, lubrication, and removal of chips.

A broaching lathe has been developed by Wickes Bros. for rough and finish turning, filleting, facing, and shouldering external cylindrical surfaces of various machine parts such as crankshafts. As the work slowly rotates, the broaches mounted on a vertical slide are forced tangentially past the work.

BROACHES (CUTTERS)

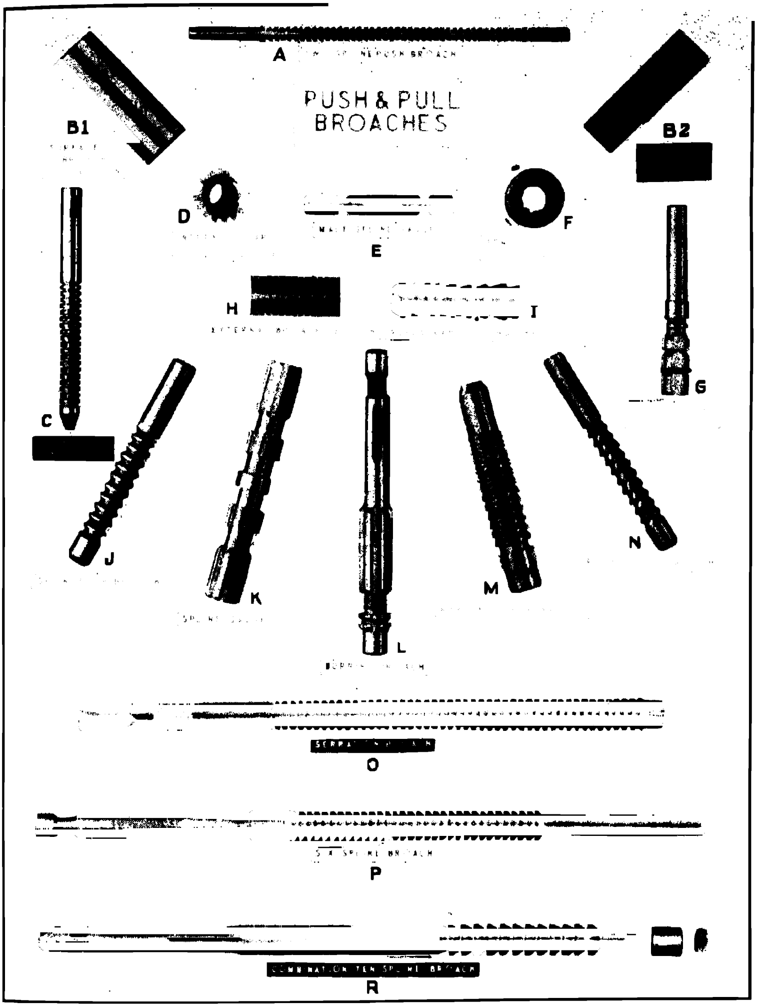
Classification

A broach may be classified in various ways, as:

1. Pull, push, or stationary.
2. Internal or external.
3. Solid or built up of replaceable sections.
4. Single-purpose or combination.
5. Roughing, sizing, or burnishing.

Push broaches are usually shorter than pull broaches and must have a relatively low ratio of length to cross section for sake of stiffness. Push broaches are employed ordinarily where only a small amount of metal is to be removed. Where one long pull broach may finish a cut, a set of several short push broaches may be required to be used successively to remove the same amount of metal. Comparatively short broaches are desirable and used where possible, as they are easier to make, harden, and handle. Various push-type broaches for internal surfaces are shown at *A*, *C*, *J*, and *M*, Fig. 10. A large push-type external-surface broach is shown being used in connection with a special fixture in Fig. 6.

Pull broaches are usually long and have many teeth. They are used to remove a considerable quantity of metal and ordinarily to



Courtesy Ex-Cell-O Corp.

FIG. 10. A Group of Push and Pull Broaches and Gages Used in the Automotive Industry.

The names and uses of the various broaches are given in the text.

finish a surface with one pass. Pull broaches for internal surfaces are illustrated at *O*, *P*, and *R*, Fig. 10. A pull broach for external surfaces is shown in Fig. 16.

Broaches are made in a wide variety of sizes and shapes. A pull broach may be as small as 4½ in. long and ⅛ in. diam., but a large solid pull broach may be 6 ft in length and up to 5 or 6 in. in diam. Many large broaches are made of built-up sections to facilitate manufacture, reduce trouble in heat treating, and permit replacement of worn-out sections. Replaceable shanks are now being provided by one manufacturer on broaches used in quantities. This reduces the length of the broach and its cost, as one shank will outwear many cutters. The class and use of each broach shown in Fig. 10 are as follows:

A. Two-spline push broach for use on any work where the length of hole to be broached is short or where the splines are not very deep.

B. Surface broach sections, two for use on shifter rod in transmission, and two for broaching three grooves.

C. Round push broach for use on short work in a press. The broach is designed so that it can be stripped through the work on the return stroke.

D. Internal gear punch for use in blind holes where a broach cannot be pulled clear through the part. Where this type is employed, the splines or teeth are first drilled in the parts so that not too much stock will have to be removed by the punch. Often a set of two or three punches is required.

E. Male spline gage.

F. Female spline gage.

G. Four-spline push broach used to remove burrs only.

H. External broach section for use on body of shock-absorber wing shaft.

I. Replaceable sizing shell for use on almost any type of round broach where a small limit is allowed on the part.

J. Spline push broach for broaching three small oil grooves in a part of approximately the same length as the front pilot.

K. Spline gage. The lower end is for checking outside diameter, *go* and *no go*. The upper end is for checking width of spline, *go* and *no go*.

L. Burring pull broach for removing burrs. The solid splines serve as guides.

M. Hardened-gear push broach for use in removing scale from and sizing hardened gears.

N. Round push broach for any kind of job where a small amount of stock is to be removed, and where the part is not too long.

O. Serration pull broach for broaching serrations in a hole about 1 in. long in a steering-arm lever.

P. Six-spline broach. Hard-gear broach for use in hardened gears for removing scales and burrs.

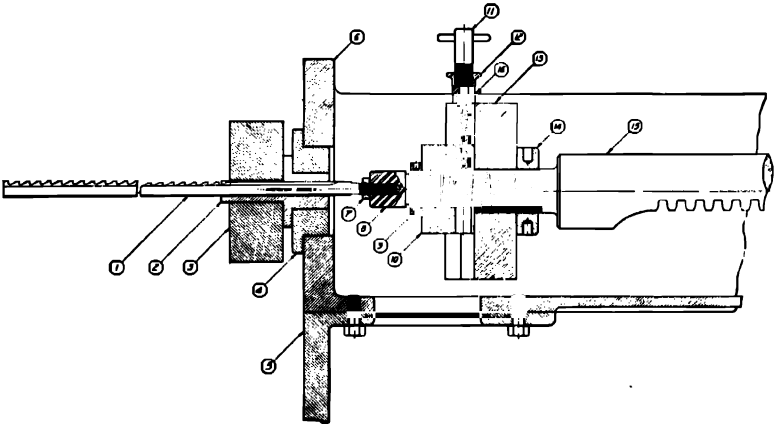
R. Combination ten-spline broach for removing burrs on the spline and around the hole in soft gears.

Pull broaches are connected to the drawbar or ram of the broaching machine by means of a **pulling head** in one of several ways:

1. A threaded-end connection for permanent setup where the broach does not have to be removed for each pass, as in keyway cutting. A threaded-end connection into which a keyway broach is fitted is shown in the sectional view of Fig. 11.

2. A bushing with through key slot and key where the pull end of the broach has to be inserted through the work before broaching, as shown in Fig. 12. Broach O, Fig. 10, has a shank for use with the key-type pull head.

3. Grooved or necked end automatically to engage the jaws of a broach pulling head. A 2-jaw spring-operated automatic pulling head



Courtesy American Broach and Machine Co.

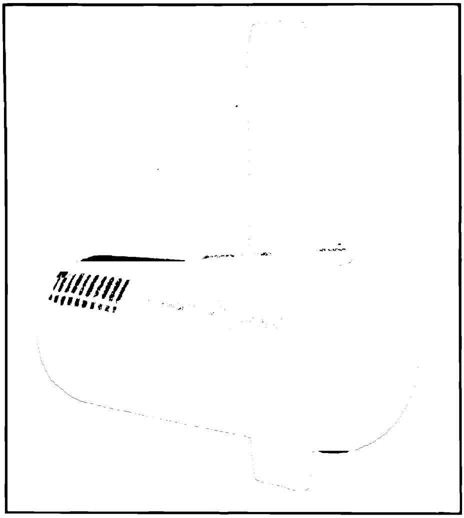
FIG. 11. A Section through the Pulling Head of the Horizontal, Rack-Type Pull-Broaching Machine as Set Up with a Threaded-End, Single-Keyway Broach.

The work 3 has been placed over the single-keyway broach and mounted on the work bushing 2. The setup is shown ready to draw the broach to the right through the work.

1. Keyway broach.
2. Work bushing, which supports the work.
3. Steel blank to be keyseated.
4. Reducing bushing.
5. Base of machine.
6. Face or working end of the machine.
7. Check nut.
8. Pull bushing.
9. Pull bushing lock nut.
10. Vertical adjusting head.
11. Screw for adjusting.
12. Lock nut for locking adjustment.
13. Pull head.

for broach shanks having two flats is illustrated in Fig. 13. In a 4-jaw type of pulling head, the jaws are locked or released by a sliding sleeve. Broaches having necked shanks, Fig. 14, are used in this type of pulling head.

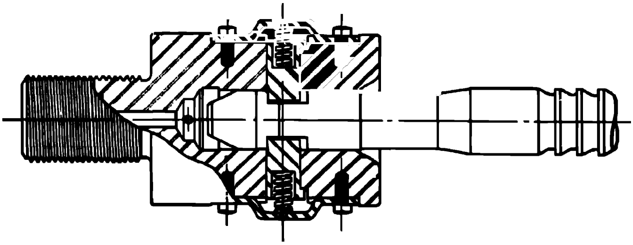
Combination broaches are designed to permit two types of cuts, such as size and burnish a hole, or size the hole and broach internal gears or splines, in one pass of the broach. The internal gear broach, Fig. 14, is designed to finish the work from a hole drilled or reamed to the pilot size. The cutting time is about 20 sec. At the pull end of the broach are a number of coarse-pitched roughing teeth for enlarging the hole, followed by a few fine-pitched finishing teeth for sizing the hole. The remainder of the broach is for rough and finish broaching the true form of the internal involute teeth. The dimensions of these broaches are held to 0.0003 in. on the splines, outside diameter to 0.0001 in., and the accumulated error in the spacing of



Courtesy American Broach and Machine Co.

FIG. 12. A Key Type of Pull-Broach Bushing.

This type of pull-broach bushing is commonly used for pulling broaches, such as multiple-spline, round, and square, the pulling ends of which have to be passed through the opening of the work before pulling. The threaded end of the bushing engages the vertical adjusting head, part 10, Fig. 11. The slotted ends of the pull broaches, shown at *A*, Fig. 10, are inserted in the opening of the bushing and held in position by the loose-fitting transverse key.



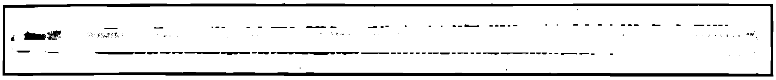
Courtesy Colonial Broach Co.

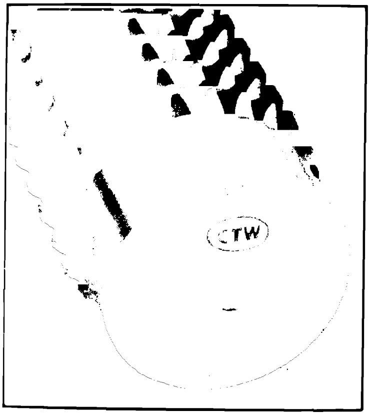
FIG. 13. A Hy-Speed Automatic Broach Puller.

The two opposed keys backed by springs in the puller body drop in the flat grooves on the broach shank as it is inserted. The broach is turned 90 deg to expand the keys to be removed. The threaded end engages the adjustable head as shown in Fig. 11. The pulling faces of the groove in the broach shank are undercut 5 deg.

the teeth not to exceed 0.0002 in. The first section to finish the bore removes approximately 0.045 in. of stock. Because involute teeth on a shaft (and on the broach for producing the mating part) can be finished to very accurate shape and size on gear-finishing or lapping machines, they are being used increasingly for spline shaft and running gear drives.

Broaches may be made of **one solid piece or of built-up sections.** Small broaches usually are made from the solid. However, in large production where extreme accuracy is required in round broaches, replaceable shells may be used, as illustrated in Fig. 10. Large surface cutters, Fig. 6, may be built up of replaceable sections. These sections are mounted in a heavy solid-back broach holder which slides in a fixture or which is bolted directly to the slide in Fig. 8. This latter 30-in.-long broach is composed of five sections, each section being 6 in. long. The face of each tooth is ground for sharpening, and after several grinds is undersize so only the lower section or roughing teeth are discarded, the remaining sections moved down, and a new section put in at the top as a finisher. This method provides an entirely new broach by supplying a single section at very low cost.





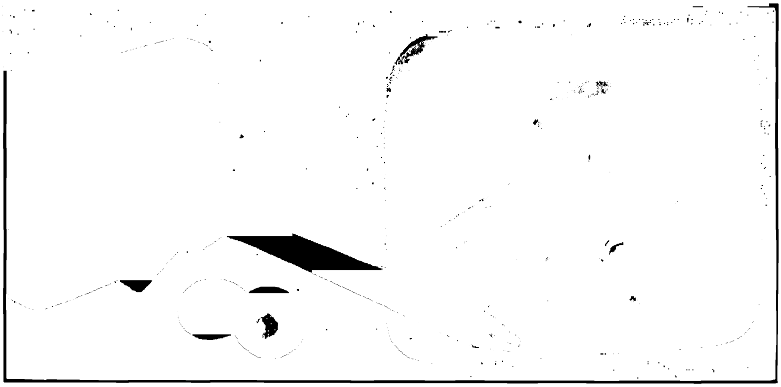
Courtesy Continental Tool Works, Division of Ex-Cell-O Corp.

FIG. 14. A Combination Pull-Type Broach for Internal Involute Gear Teeth, with an Enlarged View of the Finishing End at the Left.

The first part of the broach roughs and finishes the round bore from a drilled hole, and the second part finishes the gear teeth in one pass. This is a standard involute tooth form of 7 diametral pitch, 20-deg pressure angle, 21 teeth, 3.000-in. pitch diam., 3.3856-in. outside diam., and 2.7142-in. root diam. The cordal thickness of the tooth is 0.2242 in. as measured with a gear-tooth Vernier set to a depth of 0.1694 in.

In order that the inner bore being broached may be **concentric** with the outer surface, such as the spline or gear teeth, drift bearings or intermediate pilots, sizing shells, and finishing teeth are used.

There are two general types of broaches for surface machining, internal and external. **Internal broaches** are of either the push or pull type. Broaches of this type are now being used to produce single and multiple keyways for permanent fit to slide under no load, or to slide under load; round, square, rectangular, hexagonal, T-shaped, and various other shaped holes such as serrations and internal gears. In the majority of cases, only a single bushing is required for this internal work as the broach follows the hole through the work and does not need to be guided by a holding fixture. For some accurate work, rough broaching is done before hardening, and light finish broaching and sometimes burnishing are done after hardening. The broach *M* in Fig. 10 is of this type. Helical splines are broached, using a roller-guide fixture, Fig. 15, by rotating the cutter as it is pulled through the work by means of a master lead screw, or by allowing the helical teeth of the broach to rotate the broach as it is pulled by a ball-bearing pulling head.

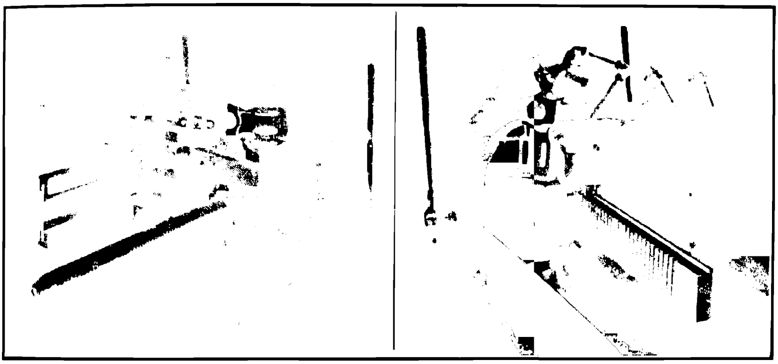


Courtesy National Broach and Machine Co.

FIG. 15. A Fixture and Broach for Broaching Helical Splines.

The drop-forged steel gear blank being broached rests against the fixture by the pulling action of the cutter. The helical broach is forced to rotate positively by three rollers of the fixture which engage helical recesses in the broach. Holes made in this way can be held to less than 0.0005 in. in size and match the size of the broach for accuracy and helix.

Surface or **external broaching** is being used on many kinds of plain and irregular surfaces. This field is becoming very broad and covers work such as broaching the square surfaces on the driving ends of shafts, openings on the ends of solid wrenches, notches on transmission shifter rails, serrated surfaces on pipe wrenches and pliers, teeth on automobile steering-arm levers, and similar work. Suitable holding fixtures must be used with external broaches for holding the part rigidly in position with respect to the broach during the operation. In designing fixtures, provision often can be made to take a range of broaches to do different operations on the same part. In some instances, several pieces can be finished at each pass of the broach, thereby greatly increasing the production, Fig. 16.



Courtesy National Broach and Machine Co.

FIG. 16. The Cutters and Fixtures for Broaching a Malleable Cast-Iron Steering-Column Support on a Duplex Horizontal-Type Machine.

At the right the serrated grooves are being cut with a surface broach. The part is then moved to the setup shown on the left, where the elongated hole, consisting of two half circles connected with two flats, is broached, after which the part is moved to the left side of the machine, where the two flat portions are removed so that the separated cap is carefully shaped to fit the body part.

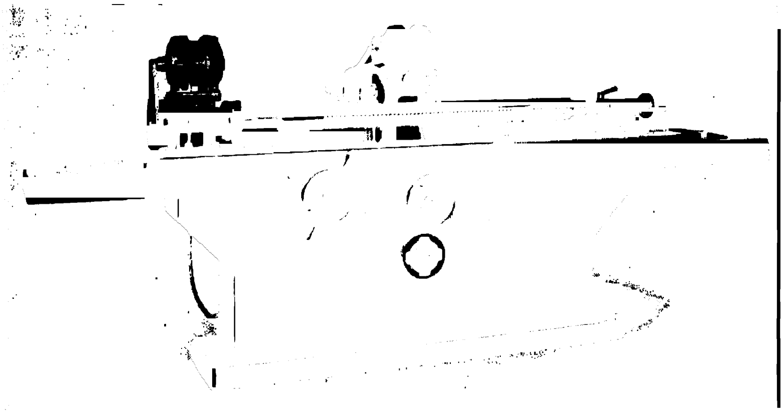
Broach Material, Heat Treatment, and Grinding

Broaches are made from several grades of tool steel. For light work in small quantities, regular carbon tool steel or carbon-vanadium tool steel is used. A finishing steel commonly is used for small-lot heavy-duty work. For high-production or heavy-duty jobs, high speed steel is used. For difficult operations, particularly on abrasive nonmetallic materials, such as hard rubber and phenol resinoids, the broach teeth may be tipped with sintered carbide.

One of the most important operations in the manufacture of a broach is its **heat treatment** and subsequent finishing by grinding. On long pieces of steel, there is a tendency for the tool to distort during heat treatment. Vertical electrically controlled furnaces with controlled atmospheres have been developed for reducing distortion and nonuniformity to a minimum. Short broaches, as a rule, are heat treated in a horizontal type of furnace.

High speed steel broaches of more than average length usually are air quenched, to avoid excessive warpage, in a cage formed of four long perforated pipes, the hot broach being hung in the center between them and subjected to an air blast through perforations in the pipe from an air pressure of 100 psi.

Grinders for finishing and sharpening broaches after heat treatment have been developed so that extremely close limits are maintained on commercial broaches. Broaches for internal work have lapped centers on which they are supported for grinding. A cylindrical grinder, either standard or special purpose, as shown in Fig. 17, is used to grind the outside diameter, the face, the fillet, and the back of the teeth, and the relief in successive positions of the wheel. Notches, splines, and serrations are ground on a surface grinder reciprocating the work under the formed wheel placed in the plane of the broach. A device with diamonds is located on one end of the table for truing the wheel periodically.



Courtesy The Lapointe Machine Tool Co.

FIG. 17. A Universal Broach-Sharpening Machine Designed for Sharpening All Kinds of Broaches.

The maximum length between centers is 60 in. It is arranged for a ¾-hp motor for driving the wheel spindle and a ½-hp motor for driving the headstock. The standard equipment consists of one 3-in.-diam. cup wheel and one 6-in.-diam. dish wheel, one 4-in. 4-jaw independent chuck mounted, and centers. The setup illustrates a dish wheel being used to grind the face of the teeth of a sizing spline broach. The wheel spindle is universal in that it may be set at any angle in a vertical or horizontal plane.

Broach Design

The design of each broach is determined by considering the following factors:

1. Material to be broached — hardness or toughness.
2. Type of hole — cored, drilled, punched, or surface.
3. Amount of stock to be removed.

4. Length of surface to be broached.
5. Accuracy and finish desired.
6. Type of machine to be used.
7. Type of feed — mechanical or hydraulic.
8. Anticipated rate of production.

The main **tooth elements** of the broach are (Fig. 18):

1. Pitch of the teeth.
2. Rise per tooth.
3. Rake angle.
4. Relief angle.
5. Chip space.

Figures 19, 20, and 21 show drawings of the three types of broaches, giving features of design.

The **pitch** of the teeth, that is, the distance from one tooth to the next, depends upon the tooth strength, length of cut, and shape and size of chips. The pitch of the roughing teeth should be as coarse as possible to provide ample chip clearance, and at least two teeth, and preferably three, should be in contact with the work at all times. Finishing teeth are often of less pitch to reduce the length of the broach.

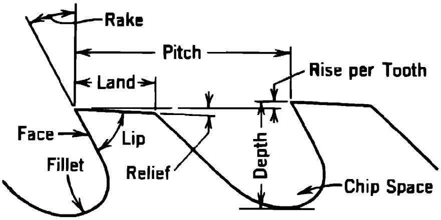


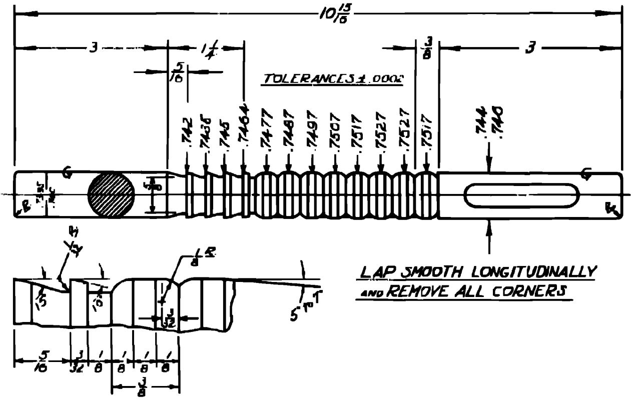
FIG. 18. The Nomenclature of the Teeth of a Broach.

The formula $p = 0.35\sqrt{l}$, in which p is the pitch of the roughing teeth in inches and l is the length of the hole or surface broached in inches, is used by a number of broach manufacturers. Sometimes, to avoid chatter when broaching hard metal, the pitch is varied slightly above and below the normal value, as is done in spacing reamer teeth unevenly.

When thin stock is being broached, it is desirable to form the teeth at an **angle**, as in a helical-gear rack. This permits greater spacing of the teeth and at the same time maintains two or more teeth in cutting contact with the work. Thin parts may be stacked so that the length of the surface being broached is three times the pitch of the teeth.

A large smooth **fillet** should be provided at the bottom of the tooth space to curl the chips and prevent their clogging. This is most important on ductile metals, such as soft steel, copper, and aluminum.

The front faces of the teeth are given a **rake angle** of 5–15 deg for general work, thus reducing the power consumption and producing smoother surfaces. Angles up to 15 deg are better on ductile metals, and smaller angles are used on cast iron, brass, and bronze.



Courtesy The Lapointe Machine Tool Co.

FIG. 19. The Design of a High Speed Steel 0.752-in.-diam. Round Finishing and Burnishing Broach of the Push Type for Use in Bronze.

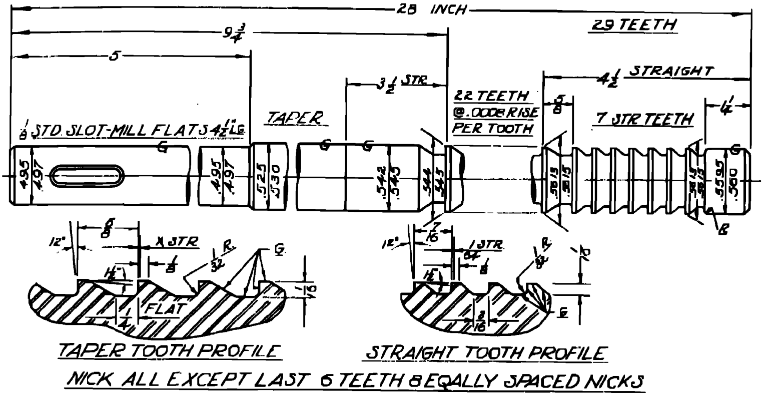
There are three cutting teeth and eight burnishers, the details of which are given on the enlarged insert.

The relief angles of broach teeth are relatively small, varying from 1 to 3 deg. The tapered cutting teeth have a relief, while teeth with no rise often have a land with no relief so they will retain size after sharpening by repeated grindings on the face of the tooth. Each broach of this type of high speed steel will give a total production of 40,000–80,000 pieces from several grinds. The same broach made with relief on the finishing teeth will be undersized after one or two grinds with a total production of 6,000–9,000 pieces.

The lands and cutting edges of the roughing teeth of most broaches are **nicked** alternately so as to break up the chips into narrow widths.

BROACHING PRACTICE

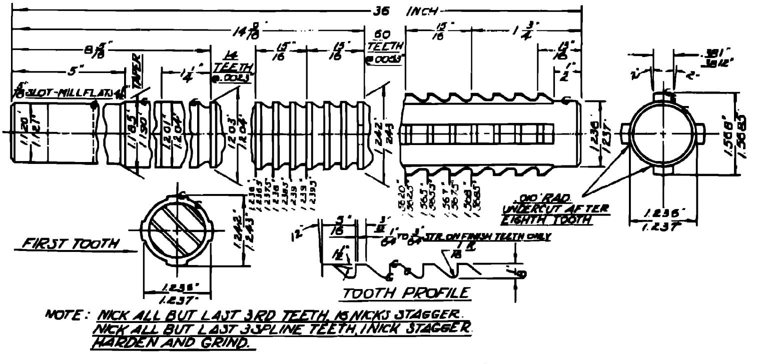
The Illinois Tool Co. recommends the practice of leaving approximately 1/64-in. stock on the diameter in a hole or on a surface in order to clean up and produce a good surface by broaching. Broaches for keys, splines, internal gear teeth, etc., cut to greater depths beyond the finished bore. Many times rough forgings or castings are finish broached, and may require a greater depth of material to be removed



Courtesy The Lapointe Machine Tool Co.

FIG. 20. The Design of a High Speed Steel 0.561-in.-diam. Round Pull Broach.

This broach is used for broaching a hole in steel 3½ in. in length. The broach is heat treated to a hardness of Rockwell C 63-65. The shank end is provided with a ⅛-in. standard slot for use in the key-type pulling head.



Courtesy The Lapointe Machine Tool Co.

FIG. 21. A Combination 1.239-in. Round, 4-Spline Broach of High Speed Steel for Cutting Steel 1¼ in. Long.

in order to clean up. The condition of the hole or surface before broaching must be considered.

The **rise per tooth** (feed) or increase in height of one tooth over the next depends largely on the thickness of stock to be removed, the number of roughing teeth in the broach, the hardness and toughness of the material to be broached, the length of the surface, and the finish desired. The harder the material, the less the stock that can be removed per tooth. The roughing operations, or first cuts, should take thick chips, while for final cuts by the finishing end, the feed per tooth is reduced, with the last few teeth of the same height. The feed per tooth for heavy work, where a heavy strong broach is used, can be greater than for light work or where a small-sectioned broach is used.

For medium-sized broaches operating in steel, the feed per tooth is from 0.0005 to 0.003 in. These values may be doubled when broaching cast iron, malleable iron, or brass. Large strong broaches may remove from 0.005 to 0.010 in. per tooth. For burnishing or sizing, the increase per tooth is not over 0.001 in., and often from 0.0001 to zero. Broaches have a few teeth at the finishing end of exactly the same size in order to give a fine finish and accurate size to the work. In many cases, the finishing teeth are followed by rounded-edge burnishers.

Cutting speeds for broaching range from 3 to 50 fpm, depending upon the size and shape of the broach and the nature of the work. The noncutting return speed is from two to five times as fast.

A steel **wire brush** is often used to clean the chips from the broach teeth. The brush may be used by hand, but is often attached to the machine bed just inside the work so as to operate automatically.

A copious supply of **cutting fluid** is beneficial in most broaching operations, particularly on steel. An emulsion may suffice, but for very hard or ductile materials, sulphurized mineral oils are recommended.

In broaching **cast-iron** parts with broaches supported by a work bushing, such as for the keyway cutter in Fig. 11, or the surface broach in Fig. 16, the broach should be inverted or on edge to prevent the fine chips from abrading the back of the broach or the bushing. When broaching keyways in **tapered** holes, the work is usually supported on a tapered bushing which is inclined so that the surface of the work to be broached is parallel to the travel of the broach.

QUESTIONS

1. How may broaching machines be classified?
2. What types of drives are used in broaching machines, and which are used on the more modern types?
3. What is the advantage of the adjustable safety valve on the hydraulic-feed broaching machines?
4. What is meant by a continuous-type broaching machine?
5. What is meant by a keyseater, and how does it work?

6. In what five ways may broaches be classified?

7. Why are pull broaches usually longer than push broaches?

8. Name three ways in which a pull broach is attached to the pulling head of the machine.

9. What is meant by a combination broach?

10. Explain the purpose of broaches having built-up sections.

11. How are these built-up sections used in internal surface broaching and in external surface broaching?

12. Of what materials are broaches made?

13. What are some of the features of broach design?

14. Upon what does the feed per tooth of a broach depend?

15. What is meant by the pitch of the teeth of a broach, and upon what does it depend?

16. What are the speeds employed in broaching for average work?

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CHAPTER XIV

GEARS AND THEIR MANUFACTURE

DEFINITION

Motion is transmitted from one shaft to another by causing curved surfaces to roll one on the other. This motion is made positive by providing the surfaces with projections—teeth—which mesh. These rolling surfaces are called pitch surfaces. Wheels with such projections are called gears.

GEAR-TOOTH FORMS

Gear teeth are **classified** according to the contour of the tooth face. They are known as cycloidal, involute, and composite.

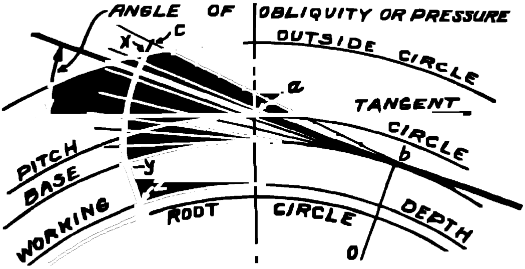

FIG. 1. Method of Developing the Involute Curve.

The pressure line ab is drawn through a on the pitch circle at the angle of obliquity with the tangent at a. The base circle yb is drawn tangent to the line ab at b. A tangent to the circle b is rolled on the base circle. Any point c on the rolling tangent describes the involute path yc.

The **involute** tooth curve is generated by rolling a straight line on a base circle, as illustrated in Fig. 1. Any point on this rolling line describes an involute curve. The tooth-face contour is then made up of that part of the involute between the outside circle and the base circle x-y, plus the straight radial or modified line y-z between the base circle and the working-depth circle, plus the fillet between the working-depth circle and the root circle.

The involute system has commercially replaced the cycloidal because the tooth curve is simple and efficient and permits center-to-center adjustment of gears.

The involute form of tooth is conveniently cut by circular form cutters as in job-shop work, Fig. 5, or by generating in production work. Four involute tooth forms have been adopted by the American Standards Association (B6.1, 1932) as follows:

1. 14½-deg full-depth tooth and composite form of basic rack (corresponds to Brown and Sharpe system), Fig. 2.
2. 20-deg stub-tooth system with straight-sided basic rack, Fig. 3.
3. 14½-deg full-depth and straight-sided basic rack.
4. 20-deg full-depth tooth and straight-sided basic rack.

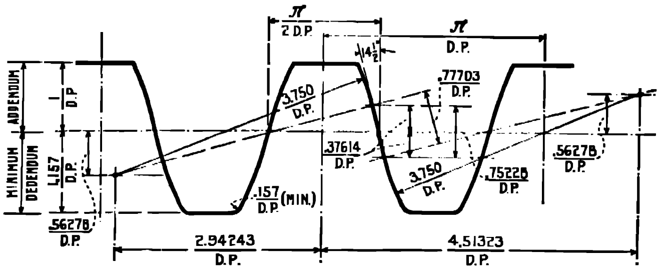

FIG. 2. The American Standards Association's Approximation to Basic Rack for the 14½-deg Composite System for Interchangeable Spur Gearing Full-Depth Tool.

The cycloidal curves which form the top and bottom of the curve are replaced by arcs of circles. For terms, see Fig. 4.

These four standard forms represent a compromise of such systems as the Brown and Sharpe, Fellows, Nuttall, Maag, and Gleason which have been in general use for years. Most of the forms are interchangeable to some extent with one of the new standards, the clearance between the top and bottom of the mating teeth being the principal cause of difference. The standards are recommended for use in future design to replace the various independent systems.

Form 1, the 14½-deg full-depth tooth and composite form of basic rack, is illustrated in the simplified form in Fig. 2. The sides of the rack teeth are slightly modified from the straight line. This system is practically identical and is interchangeable with the Brown and Sharpe Manufacturing Co. standard.

This composite form of basic rack is used principally with circular form cutters, while the straight-sided racks adapt themselves particularly to production work in which the straight-sided basic-rack generating cutter is advantageous owing to the straight-line simplicity and also to the ease with which a long addendum pinion can be calculated for the purpose of avoiding undercutting.

Forms 2, 3, and 4 all have straight-sided basic racks. The stub-tooth form (2) illustrated in Fig. 3 supersedes nine previously used stub-tooth systems. Form 4 has been adopted as the sole standard by Germany and is used in this country where strong and quiet gears are desirable.

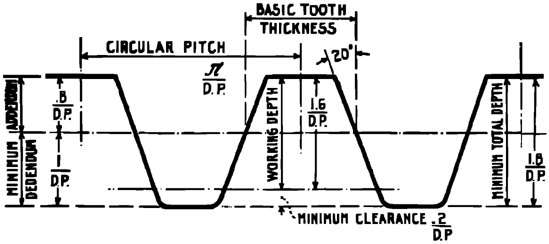

FIG. 3. The American Standards Association's Basic Rack for the 20-deg Stub Tooth Involute System for Spur Gearing.

Nomenclature and Formulas for Gear Teeth

Nomenclature of gear teeth of the involute system of spur gears is illustrated in Fig. 4. Definitions relating to the involute gear teeth are as follows:

Pitch Line or Circle — the theoretical surfaces of contact of two mating gears or rolling cylinders.

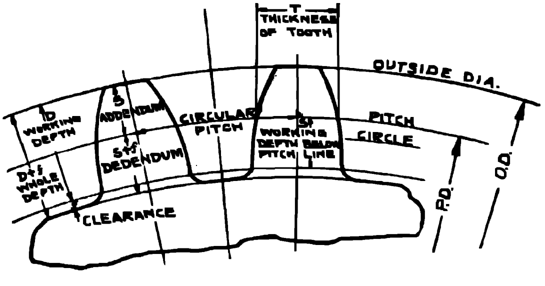

FIG. 4. Nomenclature of Gears and Gear Teeth Used in the Involute System of Spur Gears as Approved by the American Standards Association.

Base Circle — that circle from which the involute curve is developed. Diameter of base circle equals the pitch diameter (PD) times the cosine of pressure angle. See Fig. 1.

Circular Pitch (CP) — distance from the center of one tooth to the center of the next measured on the pitch circle.

$$CP = \frac{\pi}{DP} = \frac{\pi PD}{N}$$

Diametral Pitch (DP) — number of teeth N divided by the pitch diameter.

Further definitions and **formulas** for the standard full depth and stub teeth in terms of diametral pitch are given in Table 1.

TABLE 1. DEFINITIONS AND FORMULAS FOR THE STANDARD FULL DEPTH AND STUB TEETH IN TERMS OF DIAMETRAL PITCH (N = NUMBER OF TEETH)

Tooth Element		Full Depth	Stub Tooth
Name	Definition		
Pitch diameter (PD)	Diameter of the pitch circle	$\frac{N}{DP}$	$\frac{N}{DP}$
Addendum (S)	Distance from pitch line to top of tooth	$\frac{1}{DP}$	$\frac{0.8}{DP}$
Minimum dedendum ($S + f$)	Distance from pitch line to root of tooth	$\frac{1.157}{DP}$	$\frac{1}{DP}$
Working depth (D)	Depth in the tooth space to which the tooth of the mating gear extends	$\frac{2}{DP}$	$\frac{1.6}{DP}$
Minimum total depth ($D + f$)*	Working depth plus clearance	$\frac{2.157}{DP}$	$\frac{1.8}{DP}$
Outside diameter		$\frac{N + 2}{DP}$	$\frac{N + 1.6}{DP}$
Basic tooth thickness on pitch line		$\frac{1.5708}{DP}$	$\frac{1.5708}{DP}$
Minimum clearance*		$\frac{0.157}{DP}$	$\frac{0.2}{DP}$
Radius of fillet		$1\frac{1}{3}f$	

* A suitable tolerance should be considered in connection with all minimum recommendations.

The shop is interested in the **dimensions** of gears involved in cutter selection, size of gear blank, and inspection of the finished work. Such values are the outside and pitch diameter of the gear blank, diametral pitch, number of teeth, and total depth of tooth. The total depth of a 6-pitch gear of the full-depth type, form 1, is $2.157/DP = 2.157/6 = 0.3595$ in.; and of the stub-tooth type, form 2, is $1.8/DP = 1.8/6 = 0.300$ in. The outside diameter of each gear having 16 teeth would be $\frac{N+2}{DP} = \frac{16+2}{6} = \frac{18}{6} = 3.000$ in., and $\frac{N + 1.6}{6} = \frac{16 + 1.6}{6} = 2.9333$ in. respectively. The circular pitch of both gears is $\pi/DP = 3.1416/6 = 0.5236$ in.

The 20-deg stub tooth of the **Fellows gear shaper** is designated by two diametral pitches such as 6/8. The numerator 6 is used as the diametral pitch to calculate the pitch diameter, number of teeth, and circular pitch, while the denominator 8 is used to calculate the addendum, dedendum, clearance, working depth, and total depth. The Fellows 14½- and 20-deg full-depth tooth and the 20-deg stub tooth use $2.250/DP$ instead of $2.157/DP$ in the composite form, the clearance being $0.250/DP$ instead of $0.157/DP$.

CLASSIFICATION OF GEARS

Gears may be classified into three **general classes** according to the arrangement of the shafts they connect, as follows:

1. Parallel shafts.
2. Intersecting shafts.
3. Nonparallel, nonintersecting shafts.

Gears also may be classified according to **general shape**, as follows:

1. Spur gears.
    - *A*. Spur gears (axes parallel).
    - *B*. Rack (axes parallel).
2. Helicoidal gears.
    - *A*. Helical gears.
        - (1) Axes parallel — true tooth shape in diametral plane (twisted spur).
        - (2) Axes parallel — true tooth shape in normal plane.
        - (3) Axes nonparallel and nonintersecting (screw).
    - *B*. Herringbone gears (axes parallel).
        - (1) Matched teeth.
        - (2) Staggered teeth.
        - (3) Continuous teeth.
    - *C*. Worm gears (axes nonintersecting).
3. Bevel gears.
    - *A*. Straight bevel (axes intersecting).
    - *B*. Skew bevel (axes cross too close for helicoidal gears).
    - *C*. Spiral bevel (axes intersecting).
    - *D*. Hypoid bevel (axes nonintersecting).

METHODS OF PRODUCING GEARS

Gears with teeth may be produced by four general methods:

1. Cast in green sand, dry sand cores, or permanent (metal) molds, and in metal dies, as in die casting.
2. Molded (plastics).
3. Hot-rolled by a master gear.
4. Machined from castings, forgings, bar stock, stampings, or molded shapes.

Gear teeth, as cast in the foundry, are rough and inaccurate, but are sometimes used where speeds are low or low cost is essential. Permanent-mold cast gears are not made in any quantities, although many blanks are prepared by this process for subsequent machining. Hot-rolled gears are obtained by rolling a master gear with a heated gear blank. Good results are obtained, but the method is not yet used commercially to any extent. Small gears, die cast of zinc, tin, aluminum, and copper alloys, are used extensively. No subsequent machining of the teeth is necessary as the surface finish and accuracy from the carefully polished dies are satisfactory for very exacting purposes.

Machining the teeth is resorted to when accurate, dependable gears are required of brass, bronze, cast iron, steel, or laminated resinoids.

Material for Gears

Gears are made of a wide variety of materials to supply various chemical or physical properties according to operating conditions. The method of manufacture is often associated with the type of material used, as follows:

1. Cast, molded, or lamellar plastics, such as Bakelite and fiber with cut or molded teeth. For high or low speed, light loads, quiet operation, and where electrical nonconducting material is desired. May be made in large or small quantities.
2. Die castings of aluminum, zinc, or bronze as outlined above. Aluminum and zinc are used for light loads, but bronze is satisfactory for heavy loads. Large production essential.
3. Cast iron with teeth cast or cut. Used for comparatively light loads and slow speeds.
4. Brass with cut teeth for comparatively light loads and slow speeds — noncorrosive.
5. Bronze with cut teeth for high loads, as in worm wheels — noncorrosive.
6. Low-carbon steel with cut teeth, for comparatively light loads and slow speeds — low cost.
7. Low-carbon steel with cut and case-hardened teeth, for high loads and high speeds.
8. Low-carbon steel, carburized with ground or lapped teeth, for high loads, quietness, and great speeds.
9. Heat-treated steels, for heavy-duty work and high speeds. Full hardening steels, such as SAE 1030, 1045, 3140, 3245, 4130, 4640, 5130, 6145, and the steels to be carburized as SAE 1020, 2315, 3115, 3215, 4615, 2515, and 6115. Large gears are usually made of the low-carbon steels with the surface of the teeth carburized after being cut. Small gears and pinions are usually made of the higher-carbon steels and are hardened throughout by heat treating (see *Machinery*, January, 1934, p. 268).

Ring gears and pinions of the spiral bevel type are used for heavy-duty work, as in automotive differential gears. An SAE 2315 steel is often used for the gears, and either SAE 2315 or 2515 steel for pinions. These steels must be pack hardened. The steel is bought in the form of bars, cut into disks, upset, pierced, expanded, and finally forged into the shape of the blank for best results. Before heat treating, the gears are copperplated. Copperplating does not permit the penetration of carbon in the carburizing process and, therefore, permits further machining work such as drilling and threading after hardening, and it also reduces shrinkage and lessens the metallic ringing sound of gears in operation. Where the copperplate is machined off, as on the surface of the gear teeth, the surface is carburized and hardened, giving a very strong, wear-resisting tooth.

GEAR-CUTTING MACHINES AND CUTTERS

Gear-cutting machines may be **classified** as to the method used to produce the tooth contour, as follows:

1. Machines using cutters which **form** the gear teeth by producing the space of the shape of the cutter itself (nongenerating).

A. A single-point form cutter used on a planer or shaper. The tool is fed at each stroke until full depth is reached. A single-point tool also is used as a fly cutter instead of the circular cutter on a milling machine.

B. A circular form cutter, used for roughing and finishing spur and helical gears, Fig. 6, and for roughing bevel gears, Fig. 8.

C. A broach form cutter for production of internal or external work, Fig. XIII-14.

D. The Gleason Revacycle process, using a circular broach type of cutter.

2. Machines using **templets** or master formers which control the path followed by the cutting tool or tools. Used for bevel gears and coarse-pitched spur gears.

A. Single tool, Fig. 9.

B. Two tools.

3. Machines employing the **generating process** whereby the correct tooth shape is developed by the relative rolling motion of the cutter and work.

A. Rack-shaped cutter for spur, helical, and herringbone gears, Fig. 12.

B. Pinion-shaped cutter for spur, helical, and herringbone gears, internal or external, Fig. 13.

C. Hob cutter for spur, helical, herringbone gears, and worm gears, Fig. 17.

D. One or more single-point tools which act as a part of a true rack. Used mostly for bevel gears or for internal spur and helical gears, Fig. 11.

E. Circular side-cutting tool for spiral-bevel or hypoid gears, Fig. 22.

Machines Using Circular Form Cutters for Spur and Helical Gears

Gears in small quantities are often made in the toolroom or job shop, on such machines as the milling machine, planer, and shaper, equipped with special accessories. A form cutter removes the material between two adjacent teeth. When gears are produced in large quantities, special automatic gear-cutting machines are employed.

The Brown and Sharpe Manufacturing Co. established a set of 15 **form cutters for involute gears** of each diametral pitch so that any two gears having a number of teeth above 12 will operate together satisfactorily. These cutters are based on an angle of obliquity of 14½ deg and composite tooth form. For each diametral pitch, the cutters are numbered by ½ from 1 to 8, incl., depending on the teeth in the gear. Except for extreme accuracy, the whole numbers only constitute a set, as follows:

No.	8	12– 13 teeth	No.	7½	13 teeth
"	7	14– 16 "	"	6½	15– 16 "
"	6	17– 20 "	"	5½	19– 20 "
"	5	21– 25 "	"	4½	23– 25 "
"	4	26– 34 "	"	3½	30– 34 "
"	3	35– 54 "	"	2½	42– 54 "
"	2	55–134 "	"	1½	80–134 "
"	1	135 and up			

Circular form cutters for spur-gear teeth are designated first by the size of the tooth as indicated by the diametral pitch of the gear and, second, by a number indicating the range of the number of teeth in the gear it will cut. Thus, a 6*DP* No. 5 cutter will cut the spaces between the teeth of gears having from 21 to 25 teeth of 6*DP*. Values of diametral pitch for which cutters are made may range from ½ to 60, with some fractional numbers up to 4 and only even numbers above 20.

Circular form cutters for helical-gear teeth are selected on a basis of both the number of teeth in the gear and the helix angle, as follows:[5]*

$$N' = \frac{N}{\cos^2 \alpha \times \sin \alpha} \quad \text{(General)} \quad = \frac{N}{\cos^3 \alpha} \quad \text{(for 45-deg helix)}$$

in which

N' = the number of teeth for which the cutter is selected.

N = the number of teeth in the helical gear.

α = the angle of helix for the tooth in degrees as measured from a line parallel to the gear axis.

Thus, the cutter for a 19-tooth, 5*DP* gear having a helix of 46 deg 30 min should be selected for

$$N' = \frac{N}{\cos^2 46 \text{ deg } 30 \text{ min} \times \sin 46 \text{ deg } 30 \text{ min}} = \frac{19}{0.3437} = 55 \text{ teeth}$$

DP here represents the pitch of the form cutter to be used.

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* Superior numerals refer to entries in the Bibliography at the end of the chapter.

The **normal pitch** in a plane at right angles to the tooth helix is CP_n.

Example:

$$CP_n = \frac{\pi}{DP} = \frac{\pi}{5} = 0.6283 \text{ in.}$$

The **circular pitch** of the teeth of a helical gear in the diametral plane is CP.

$$CP = CP_n \sec \alpha = 0.6283 \times 1.4527 = 0.913 \text{ in.}$$

The **pitch diameter** is

$$PD = \frac{N}{DP} \times \sec \alpha = \frac{19}{5} \times 1.4527 = 5.52026 \text{ in.}$$

The **addendum**, dedendum, total depth of tooth, and outside diameter are computed as for spur-gear teeth from the DP, as shown in Table 1. Thus, the total depth of the 14½-deg full-depth tooth is 2.157/5 = 0.4314 in.

The **outside diameter** of the gear blank is

$$PD + 2 \times \text{addendum} = 5.520 + 2 \times \frac{1}{5} = 5.920 \text{ in.}$$

The **lead of a helical gear**, like the lead of a screw thread, is the axial distance between one point on the helix and the corresponding point after one revolution. For the above gear:

The lead = the pitch line circumference of the spur gear ÷ tan α = $\frac{N}{DP} \pi \sec \alpha \div \tan \alpha = \frac{19}{5} \times \pi \times 1.4527 \div 1.05378 = 16.4575$ in.

This distance is used to select the train of gears to drive the dividing-head spindle from the table lead screw, as described on p. 204.

Such helical gears are used between parallel shafts or nonparallel nonintersecting shafts. The helix angles of both gears are equal in the first case, but may be different in the second. The speed ratio of two helical gears, as with spur gears, is equal to the ratio of their number of teeth.

Example: Two gears are to be cut to connect two shafts at right angles having an 8-in. center distance with a 2 to 1 speed ratio. The N_1 tooth, $5DP$ gear, for which computations have been made above, will drive the N_2 tooth gear. Then $2N_1 = N_2$. The center distance C equals half the sum of the two pitch diameters, or

$$2C = 16 = \frac{N_1 \sec \alpha}{5} + \frac{N_2 \sec (90 - \alpha)}{5}$$

or

$$N_1 \sec \alpha + N_2 \sec (90 - \alpha) = 80$$

This equation involves unknowns N_1, N_2, and α.

$2N_1 = N_2$, and helical angle α should be about 45 deg. Then
$N_1 \sec 45 \text{ deg} + 2N_1 \sec (90 - 45 \text{ deg}) = 80$
$3N_1 \times 1.4142 = 80$, from which $N_1 = 18.85$

Since N_1 must be an integral number, it will be assumed to be 19, and then $N_2 = 38$. By trial, values of α, slightly above and below 45 deg, are tried in the equation, with values of N_1 and N_2 as indicated, until the result is equal approximately to 80. When α equals 46 deg 30 min, the equation becomes

$$19 \times 1.4527 + 38 \times 1.3786 = 79.9881.$$

The actual center distance $= \dfrac{79.9881}{2 \times 5} = 7.99881$ in., which is considered sufficiently close to 8.000 in. for this example. The cutters are then found for each gear as shown above. The work is set up in the dividing head, and the table of the universal miller swiveled to the proper helix angle of the gear on one side of the center for a left-hand helix, and the other side for a right-hand helix. An added idler in the gear train changes the direction of rotation of the gear blank from a right- to a left-hand helix.

Machines using a circular form cutter to rough or form gears are built in a variety of styles and sizes, although they operate quite similarly.

The most general way of cutting relatively small spur gears in job-shop work is illustrated in Fig. 5. The gear blank has been turned to the correct outside diameter in accordance with the formulas given in Table 1. The cutter, selected for diametral pitch and number of teeth, is mounted on the arbor. In the illustration an intermediate arbor support is shown being used in addition to the end support. After setting up the dividing head on the table, the table is moved horizontally and transversely to locate the headstock center in the same vertical plane with the center of the face of the cutter tooth. The central line on the outside of the cutter teeth is used for this purpose. The table is next lowered and the mandrel carrying the gear blank is mounted on the dividing-head centers. The table is raised so that the bottom of the rotating cutter just makes contact with the top outside diameter of the work. After moving the work to the cutting side of the cutter, the table is raised an additional distance equal to the depth of cut. In this position, the knee gibs are clamped to the column. The proper cutting speed and feed are then selected and the dividing head set up for appropriate indexing. After each cut, the cutter is returned to the cutting side of the work and the work indexed one tooth space.

In extremely heavy work, because of coarse pitch or tough material, a roughing cut all the way around may be made, using a shallow depth of cut and then taking the finishing cut to the full depth. The roughing and finishing cuts may be made on the same pass as shown in Fig. 6. Roughing or stocking cutters are used in production work to rough out the teeth to approximate form because of their ability to cut at faster speeds and coarser feeds. Such cutters may be furnished with teeth having steps on both sides of all teeth, stepped on one side of each alternate tooth, and teeth alternate right and left helically gashed to provide side rake. Thin cutters with a hook also are used. Worn circular form cutters often are used for roughing out the gear which may then be finished on another similar machine with a new accurate form cutter or on generating machines employing a hob, rack, or pinion cutter.

Courtesy Cincinnati Milling Machine Co.

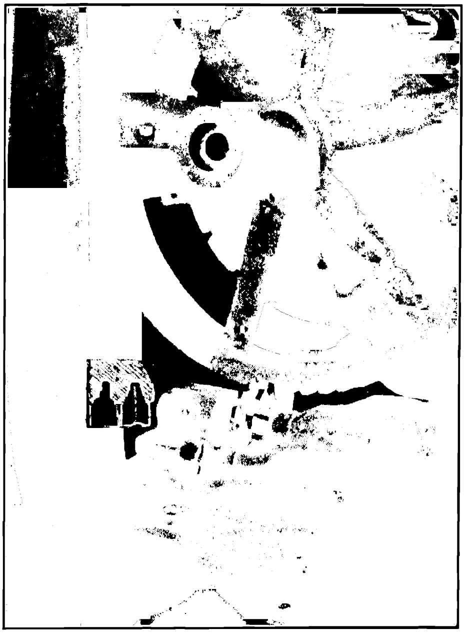
FIG. 5. A Setup Showing the Common Practice of Cutting Spur Gears in a Knee-Type Milling Machine Using the Dividing Head to Index the Blank for Tooth Spacing.

A circular form cutter is mounted on the arbor while the gear blank is mounted on a mandrel in turn supported on the centers of the dividing head. A dog on the rear end of the mandrel has its tail clamped to secure it to the headstock spindle with no backlash.

Where many gears are being made, machine tools designed for the specific purpose and range of work are used. The dividing head, for automatically indexing the work from one tooth to the next, is built into the machine as an integral part with provisions for necessary change gears. Circular form or stocking cutters may be fed horizontally as shown cutting a spur gear, Fig. 6, or vertically, Fig. 8.

In these automatic machines, the cutter, rotating on an arbor, is centered with respect to the work and adjusted for the desired depth of cut. It is fed across the face of the gear blank on the cutting cycle, and then returned to the starting position at rapid traverse when the bank is automatically indexed one tooth space.

Spur-gear racks may be cut with a form cutter which is fed across the face of the rack blank. After being returned to its starting position, the work is moved forward one tooth space for the next cut.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 6. Roughing and Finishing the Teeth of a Large Cast-Iron Spur Gear on the Brown and Sharpe Automatic Gear-Cutting Machine Using Form Cutters.

The metal is roughed out by the stocking cutters on the left, but the gear teeth are finished by the finishing form cutter at the right located on the centerline of the gear. See insert. The gear blank mounted on a mandrel is driven and supported by angles bolted to the faceplate. It has 115 teeth of $2\frac{1}{2}DP$. The width of face is $3\frac{1}{2}$ in. The high speed steel cutter has 10 teeth and is $6\frac{1}{8}$ in. diam. It is fed at $5\frac{15}{16}$ in. per min, rotated at 50 rpm, giving a peripheral cutting speed of 80 fpm. The time to set up the machine is 60 min, to change blanks 15 min, and the actual cutting time is 117 min. A screw jack supports the blank rim immediately back of the cutters.

Machines Using Circular Form Cutters for Bevel Gears

A set of circular form cutters is made for cutting bevel-gear teeth. They are similar to those for spur gears, but are all stamped " bevel " and are selected from the same table for a number of teeth N' equal to the actual number of teeth in the gear N divided by the cosine of the pitch-cone angle b, Fig. 7. The teeth of these cutters are thinner than the corresponding ones for spur gears, as they must pass between the teeth of the bevel gear at the small end.

The teeth of bevel gears constantly change in circular pitch from their large to small end. For this reason, it is impossible to cut gears whose tooth curves are theoretically correct with rotary cutters having fixed curves. In the job shop where bevel gears are produced on a milling machine with the work held in a universal dividing head, the first or central cut to depth is made with the " bevel " form cutter. The gear teeth must then be recut on each face after moving the gear and table off center from the cutter and then rolling the tooth face back toward the cutter.[5b] The finished tooth form is then obtained by hand filing.

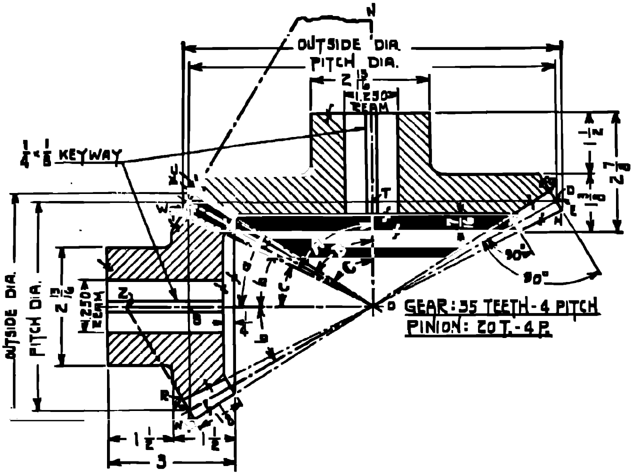


Fig. 7. Nomenclature of a Mating Bevel Gear and Pinion.

The latter corresponds to that being machined on the Gleason form-copying machine in the laboratory. Values of the elements for shop use are computed in the text. The tangent of the pinion pitch-cone angle *KOS* equals the tangent of *b* equals *KS/OS* equals $\frac{\text{the number of teeth in the pinion.}}{\text{the number of teeth in the gear.}}$

The calculations of such elements of the bevel gear and pinion as are needed in the shop are as follows, when referring to Fig. 7, in which the large gear has 35 teeth and the small gear or pinion has 20 teeth, both of 4 pitch.

The **pitch-cone angle** b of the pinion is KOS, and B of the gear is TOF.

The **pitch diameter** of the gear is $\frac{N}{DP} = \frac{35}{4} = 8.750$ in.

That of the pinion is $\frac{N}{DP} = \frac{20}{4} = 5.000$ in.

The **tangent** of the pitch-cone angle KOS of the pinion is $\frac{KS}{OS} = \frac{5.000}{8.75} = 0.5714$.

Then angle KOS is 29 deg 45 min.
Angle TOF = 90 deg − angle KOS = 60 deg 15 min.

The **pitch-cone radius** $OF = FS \times$ cosec of angle $KOS = \frac{5}{2} \times \frac{1}{\sin KOS} = \frac{5.000}{2} \times \frac{1}{0.4962} = \frac{5.000}{0.9924} = 5.0383$ in.

The **addendum** KP or FX of the pinion and DE or FW of the gear teeth $= \frac{1}{DP} = \frac{1}{4} = 0.250$ in.

The **dedendum** FU of the gear teeth and FY of the pinion teeth $= \frac{1.157}{4} =$ 0.28925 in.

The **total depth** XY for the pinion teeth and WU for the gear teeth = 0.53925 in.

The **turning angle** a of the pinion is XOS. $a = b +$ angle FOX.

The cotangent of angle $FOX = OF \div FX = 5.0383 \div 0.250 = 20.015$.

Angle FOX = 2 deg 8 min.

Then angle a = 29 deg 45 min + 2 deg 8 min = 31 deg 53 min.

The **cutting angle** c of the pinion is SOY. $c = b - FOY$.

Cotangent $FOY = OF \div FY = 5.0383 \div 0.28925 = 17.350$.

Angle FOY = 3 deg 42 min. Then angle c = 29 deg 45 min − 3 deg 42 min = 26 deg 3 min.

The **outside diameter** of the pinion is equal to the pitch diameter + (2 × addendum × cosine of the pitch angle) = 5 + (2 × 0.250 × 0.8725) = 5 + 0.4362 = 5.4362 in.

The bevel cutter for the pinion should be selected for a number of teeth equal to $\frac{N}{\cos b} = \frac{20}{0.8682} = 23$. This calls for a bevel cutter No. 5 of $4DP$.

For the production of accurate bevel gears in large quantities, the gear blanks are usually roughed out with stocking cutters, as shown in Fig. 8, and are then finish cut on the form-copying type of machine, Fig. 9, or on bevel-gear generating machines, Fig. 11.

The Revacycle process is a high-production method of forming straight-tooth bevel-gear teeth in one cut from solid metal. A large-diameter cutter has cutting teeth extended radially outward, similar to those of a form milling cutter. They are of different height and resemble a circular broach. The cutter rotates in a horizontal plane. During the cutting operation for each tooth, the blank is held motionless and the cutter is moved in a straight line across the face of the gear parallel to the root line. The desired tooth shape is produced by the combined effect of the motion of the cutter and the design of the teeth. Automobile side gears of sixteen teeth are finished at the rate of sixty per hour (*Iron Age*, July 13, 1950, p. 90).

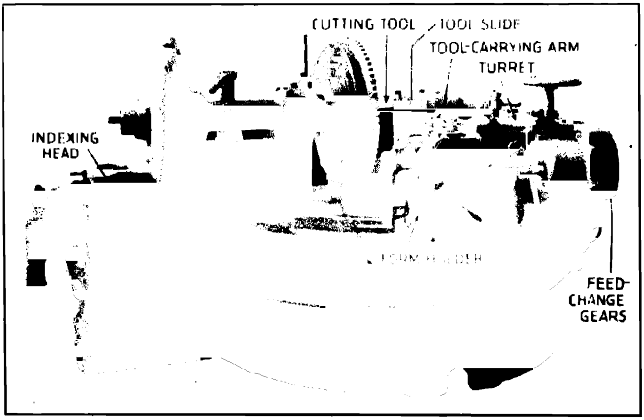
Machines Using the Form-Copying Principle

The form-copying or templet type of gear-cutting machine, Fig. 9, is used for the manufacture of both bevel and large spur gears in small

Courtesy Gould and Eberhardt.

FIG. 8. The Gould and Eberhardt No. 36-B Automatic Gear-Cutting Machine Set Up for Roughing the 24 Teeth 3*DP* of a 2-in.-Face Miter Gear.

The material is steel. The cutter is 4 in. diam. and operates at 97 rpm and 3.6 in. feed per min. The cutting time is 21.8 min, the loading time 1.5 min, making a total time floor to floor of 23.3 min per gear. After the teeth are roughed out, as shown, they are then finished on the straight-tooth bevel-gear generator shown in the background.



Courtesy Gleason Works.

FIG. 9. The Gleason 37-in. Bevel-Gear Planer of the Single-Tool Form-Copying Type Set Up for Planing the Teeth of a Large Bevel Gear.

or moderate quantities. They can be changed quickly from one job to another.

Three forms are needed for each setup. One form is straight for stocking, and two forms, the curves of which are based on the pitch angle, have enlarged profiles of the upper and lower side of the tooth to be cut. Twenty-five sets of forms of 14½-deg or 20-deg pressure angle are furnished with each bevel-gear planer. Forms of 20-deg pressure angle are furnished with the spur-gear planers. The forms are modified to overcome the undercut which the true involute develops on pinions with small numbers of teeth. These forms are mounted on a holder bolted to the bed. The holder can be indexed to bring each form into operating position as needed.

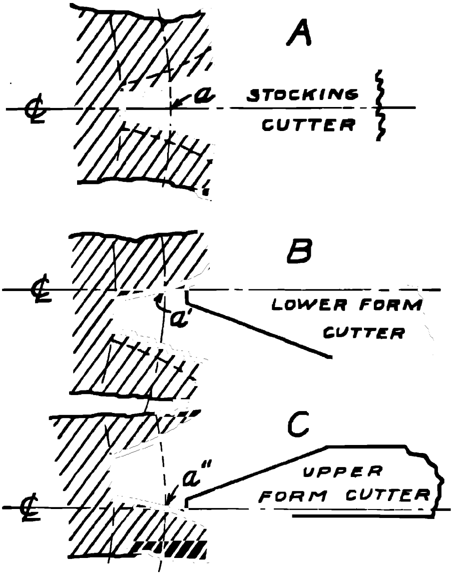


FIG. 10. The Three Tools Used with Templets on the Gleason Form-Copying Gear Planer.

At *A* the stocking cutter is being fed horizontally to depth on the centerline of the gear. At *B* the gear has been rotated until the lower pitch point *a*′, that is the intersection of the pitch circle and the involute curve, is on center. The tool is fed inward forming the involute curve of the concave templet. At *C* the upper pitch point *a*″ is on center, and the tool is fed inward along the upper tooth face by the convex templet.

Three shapes of tools are required to machine a complete gear on the form-copying planer, as shown in Fig. 10. They are set to position in the machine by means of a gage. The stocking tool is used with a straight templet. After all teeth are roughed out, the second tool is set up to operate with the concave templet for finishing the lower surface of all teeth. The third tool is then used with the convex templet for finishing the upper surface of all teeth. With each tool and templet setup, operations on all teeth of the gear are performed automatically.

In cutting bevel gears, the blank is held stationary, except for indexing. The tool-carrying arm is mounted to swing about a point coinciding with the apex center of the gear being cut. It is supported at its outer end by a roller resting on a fixed templet as the turret swings toward the blank. The tool has a reciprocating motion to cut the teeth for their full length on the forward stroke and the side feed to cut the teeth to the required depth. While feeding the tool to depth, the roll, riding on the templet, causes the tool point to reproduce the form of the templet at all points along the length of the tooth.

A revival of the old Stevenson-type **form tool** gear-cutting machine has been made by the Michigan Tool Co. in the form of its " Shear-Speed " gear-cutter. The production of this machine is practically equal to eight hobbing machines and nine finish shapers formerly used. All teeth are cut simultaneously with single-point tools of the correct tooth-space shape, being fed in radially at each stroke. The accuracy obtained makes final shaping or further finishing unnecessary (*Iron Age*, Sept. 25, 1947).

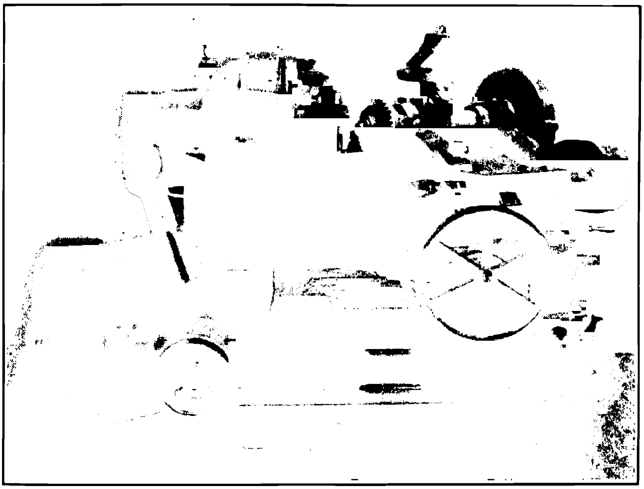
Machines Using the Generating Principle

Machines which generate with a rack-shaped cutter: Many gear-cutting machines employ a reciprocating cutter consisting of a single-point tool like the tooth of a rack, two single-point tools with cutting edges corresponding to the inner faces of two adjacent rack teeth, a rack with several teeth, or a pinion having cutting teeth about its periphery.

The Bilgram gear-generating machine uses **one single-point tool** having the shape of a single tooth of a rack, Fig. 12, attached to the end of a horizontally reciprocated ram. The gear is supported in a mechanism on the forward end of the machine to furnish the proper rolling action for cutting any type of gear and also indexes the gear blank. The gear blank is indexed during every return stroke of the tool so that no two successive cuts are made in the same tooth space.

The Gleason two-tool generator for cutting straight-tooth bevel gears and pinions in any quantity, Fig. 11, is built in 3-in., 12-in., and 25-in. capacities with an 8-in. machine built especially for finish cutting automobile differential gears previously roughed out. The **two single-**

point tools reciprocate alternately on two slides set at the tooth-thickness cone angle. The two cutters are shown swung away from the gear blank about midway between the beginning and end of the rolling action of the gear. The cutters first engage the gear blank above center where they are fed into depth; then the cutters and the gear blank roll downward together as a crown gear and pinion while one tooth is being machined on both sides. The cutters are then withdrawn from the gear blank, and returned to their upper starting position during which time the gear blank is indexed one tooth space.



Courtesy Gleason Works.

FIG. 11. The 12-in. Straight-Tooth Bevel-Gear Generator Having Two Single-Point Tools.

The Maag gear shaper made by Niles-Bement-Pond Co. employs a rack-shaped cutter with 3–8 teeth, Fig. 12, depending on the pitch, to generate spur, helical, or herringbone gears. The front face of the rack cuts on the forward stroke as it reciprocates across the face of the blank. It thus cuts away the metal generating the tooth profile. In starting the first cut, the cutter is gradually fed in radially to depth after which the depth is constant while the gear rolls slightly on the cutter at each traverse. When the blank has advanced a distance equal to one or more circular pitches, the table returns it to its starting point without rotary motion. The same cutter is used for both gear and pinion. For different ratios, however, cutters are used in which the pressure angle varies from 15 to 30 deg as the ratio changes. For ordinary ratios, three cutters generally are required per pitch. The faces of the teeth are finished by numerous thin cuts. That portion below the base circle indicated as y-r in Fig. 1 is generated by the outer end of the cutter tooth.

Machines which generate with a pinion-shaped cutter: The Fellows gear shaper, employing a pinion-shaped cutter, is used extensively in the manufacturing industry for generating both internal and external spur and helical gears, cluster gears, herringbone gears, splines, cams, etc.

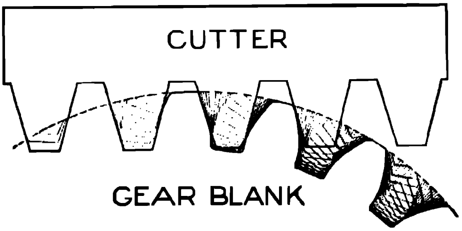
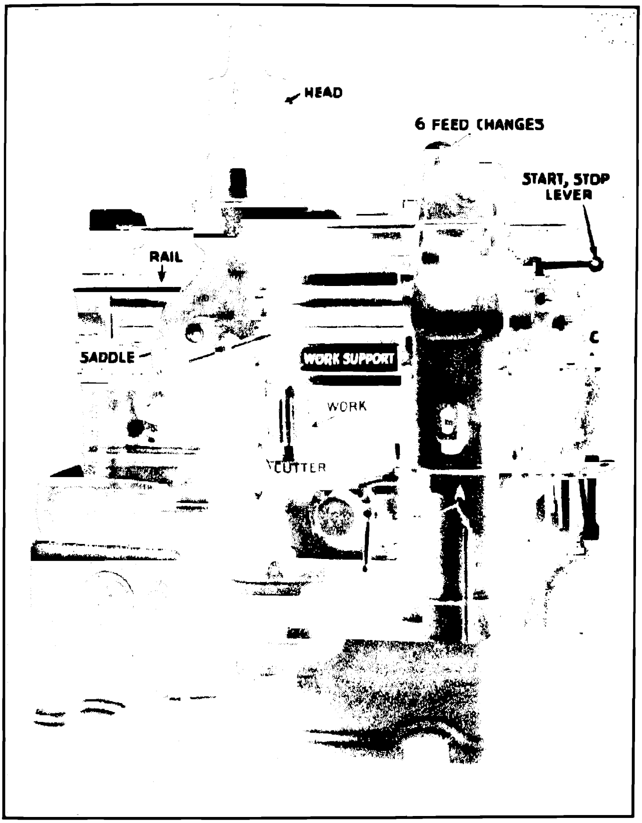


FIG. 12. A Rack-Type Cutter Generating the Teeth of a Spur Gear.

The cutter mounted on the lower end of the vertical ram reciprocates vertically and rolls continuously with the gear blank in a manner similar to that of the rack cutter, Fig. 12. The standard machine is adapted to cut both spur and helical gears with external or internal teeth, as well as herringbone gears. When limited for cutting spur gears with a 5-in. external face of *4DP* and 3-in. internal face of *5DP*, as illustrated in Fig. 13, it is known as No. 61A. This machine uses 3-in. *PD* cutters for *7DP* and finer, and 4-in. cutters for *6DP* and coarser. Both cutters have a 1¼-in. hole. Three guide heads may be used interchangeably — one with a straight guide for spur gears and one each for a left- and right-hand helix.

There are available four values — 111, 184, 270, and 342 — of cutting-speed strokes per minute of the cutter. The slower speeds are used with the longer strokes and harder materials. Cast iron cut dry requires slower speeds than steel flooded with a cutting fluid. There are six feed strokes — 720, 900, 1,080, 1,260, 1,440, and 1,620 — per revolution of the cutter.

The number of strokes of the cutter per inch of its pitch diameter is found by dividing the feed strokes by the pitch diameter of the cutter. Finer feeds must be used where rigid support of the work is lacking. For highest-quality gears, two cuts around should be made. For small lots the two cuts may be taken on the same machine, but for large lots the gears should be roughed on one machine and finished on a second. For ordinary or low-quality work the gears may be finished in one cut around. The gear blanks must be machined accurately to have the hole square with the face, and concentric with the outside diameter.



Courtesy Fellows Gear Shaper Co.

A, apron withdrawing lever and socket; *B*, apron locking lever; *C*, pitch dial for tooth-depth setting.

FIG. 13. A Front View of the No. 61A (6A-Type) Gear Shaper Used in Generating Gears with a Pinion-Type Cutter.

This machine is designed for the production of gears in quantities up to 18 in. pitch diam. The illustration shows the machining of a steel gear made from SAE 1045 bar-stock steel, of ¾ pitch, 20-deg pressure angle, 20 teeth, having a 5-in. face. One gear is machined at a time and finished in two cuts without removal from the machine. The cutting speed is 111 strokes per min, giving a surface speed of approximately 92 fpm. The feed is 1,080 strokes per rev of the cutter, or 270 strokes of the cutter per in. of pitch diameter for the 4-in.-pitch-diameter cutter. The cutting time per gear is 37½ min, the handling time is 1½ min, making the total time floor to floor 39 min per gear. A cutting fluid consisting of 2 parts refrigerant base oil and 8 parts paraffin oil is used.

Two independent motions are provided for the feed of the cutter: the depth feed by which the saddle carrying the cutter is fed into the work to the correct depth, and the rotary feed by which the cutter and gear blank are slowly rotated in unison. On the 6A machine, the feed mechanism is so arranged that the cutter can be fed in automatically for the roughing cut and, after the gear has made one complete revolution, the cutter is fed in to full depth for the finishing cut. Upon completion of the second revolution of the gear blank, the tripping mechanism automatically stops the entire machine. The apron carrying the blank is withdrawn from the cutter to give relief on each noncutting stroke.

The Fellows No. 7 high-speed gear shaper is limited to smaller work and operates much faster than the standard machine.

A rack-cutting machine is manufactured by the Fellows Gear Shaper Co. to cut racks up to 4-in. face and 72 in. long. A pinion-type cutter reciprocates vertically as it rotates slowly. A rack blank clamped to the table advances tangentially into the cutter, the teeth being generated on the side of the blank.

The pinion-type cutter, Fig. 14, is made for spur or helical gears, with a hole for arbor mounting. Cutters of small diameter or internal work are made with shanks. Each cutter will cut any number of teeth of its pitch.

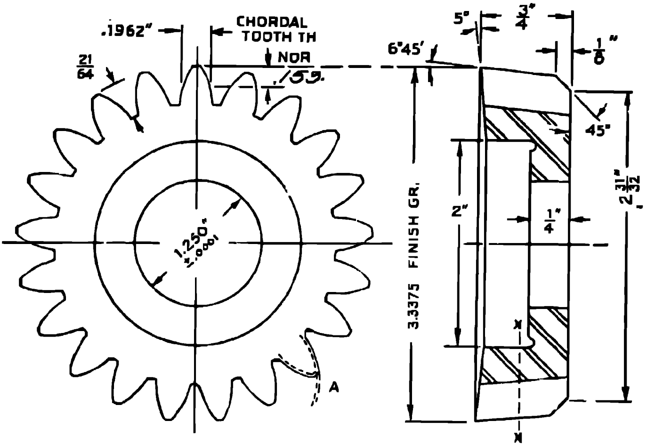
Helical cutters, Fig. 15, are required for cutting helical gears. The Fellows helical cutters are standardized for 15-deg and 23-deg helices. They are made to oscillate as they reciprocate by means of helical guides in the head at the upper end of the cutter spindle. Right- and left-hand guides are used with right- and left-hand helical cutters, respectively. The cutters will cut on either the up, Fig. 13, or down stroke. Each gear tooth of both spur and helical gears has its true **involute in the diametral plane.** The helical gears are twisted spur gears.

By means of this generating principle, cutters of various shapes can be made to cut many forms, such as splines, cams like the cam ring of a radial aircraft engine, and intermittent gears.

The Sykes gear generator, Fig. 16, employs two pinion-type cutters and operates quite similarly to the Fellows gear shaper except that it is horizontal. The two cutters are opposed and work alternately, each controlled by its own cam.

This machine is made in a wide range of sizes, the largest of which will cut gears up to 12 ft diam. It will generate spur gears, helical gears, cluster gears simultaneously, double helical gears with a center groove — with teeth matched or staggered — with helices of similar or dissimilar pitch, and the Sykes continuous-tooth herringbone gear, Fig. 16, with the two helices terminating in a sharp apex.

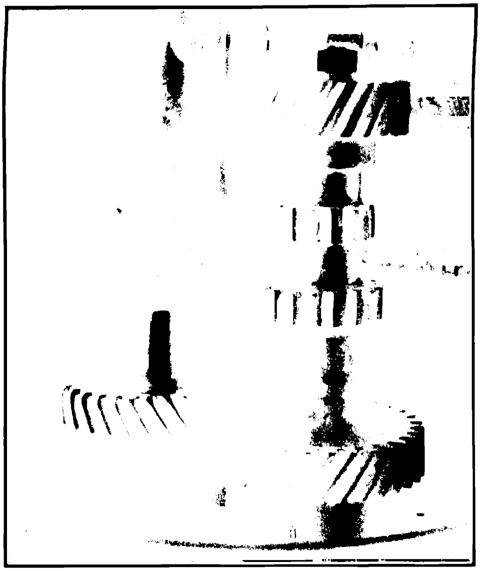
Machines which generate with a hob: Hobbing is another method of generating forms on a cylindrical base. Hobbing machines, Fig. 17, are used extensively for roughing and finishing spur, helical, and herringbone gears, worm gears, worms, ratchets, sprockets for silent chain, roller chain, and block chain, and other shapes, such as square and spline shafts. The involute-gear **hob** has cutting teeth of the same cross-sectional shape as the teeth of a rack of corresponding pitch. It consists essentially of a series of rack cutters located with lead about the periphery of a cylinder, as shown in Fig. 18. The successive hob teeth lie along a helical path like a screw thread. The hob rotates continuously about its own axis for **cutting speed.** The spur or helical gear blank and hob revolve together, the speed ratio depending upon the number of teeth in the gear and the number of threads on the hob. A single-thread hob would rotate twenty times for each revolution of a 20-tooth gear. As they rotate together, the blank is moved for feed past the hob, Fig. 17, or the hob is advanced across the face of the gear, as in Fig. 19.



Courtesy Continental Tool Works, Division of Ex-Cell-O Corp.

FIG. 14. A Pinion- or Disk-Type Cutter for Generating Involute Spur-Gear Teeth as Used on the Fellows Gear Shaper.

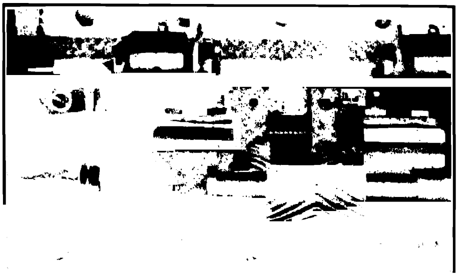
The relief is constant throughout the cutter life. The tooth thickness is reduced slightly by successive sharpenings on the face. At *A* is shown the contour of the tooth at section *xx*. Both involutes are struck from the same base circle. The cutter is sharpened by grinding only on the 5-deg raked face. This cutter has 24 teeth of *8DP*. The pitch diameter is 3.000 in., and the pressure angle is $14\frac{1}{2}$ deg. The diameter of the base circle is 2.90445 in.



Courtesy Fellows Gear Shaper Co.

FIG. 15. A Setup on the No. 75 Fellows High-Speed Gear Shaper.

This setup is to machine the large gear on the countershaft for automobile transmissions, of $3\frac{1}{2}$ per cent nickel steel, 7 diametral pitch, 20-deg pressure angle, 33 teeth, 1-in. face, and 4.714 in. pitch diam. The gear is finished in two cuts in two separate machines, this illustration showing the finishing cut. The cutting speed is 550 strokes per min, giving a surface speed of 92 fpm. The feed is 1,088 strokes per rev of the cutter. The cutting time per gear is 6.6 min, the handling time is 1.4 min, making a total time floor to floor of 8 min per gear.



Courtesy Farrel-Birmingham Co.

FIG. 16. A Close-Up View of a Small Sykes Herringbone Gear and the Two Helical Cutters in the Background as Set Up on the No. 2A Generator.

For cutting worm wheels, the hob may be fed radially toward the center of the blank, the blank fed toward the hob, Fig. 21, or a tapered hob fed tangentially across the blank, according to the type of machine or hob being used. When cutting spur gears, the hob arbor is swiveled from its position perpendicular to the gear axis, through an angle equal to that of the helix of the hob thread. When cutting right-hand helical gears, the head is swiveled an additional amount equal to the helix angle. Gear teeth generated by a hob have their **true involute in a** normal plane, i.e., perpendicular to the tooth helix.

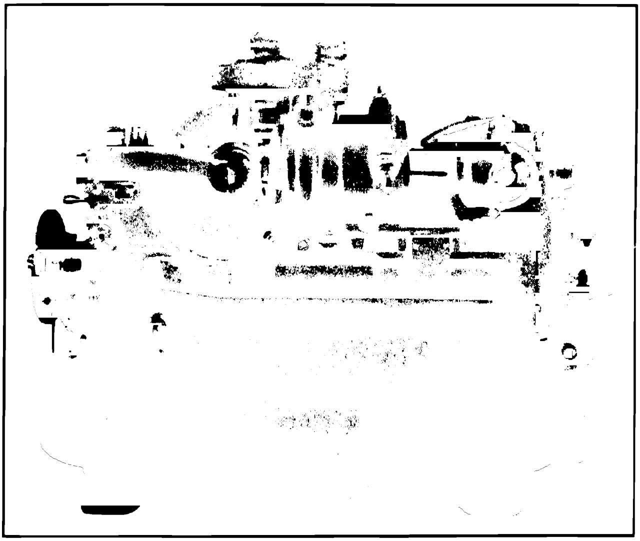
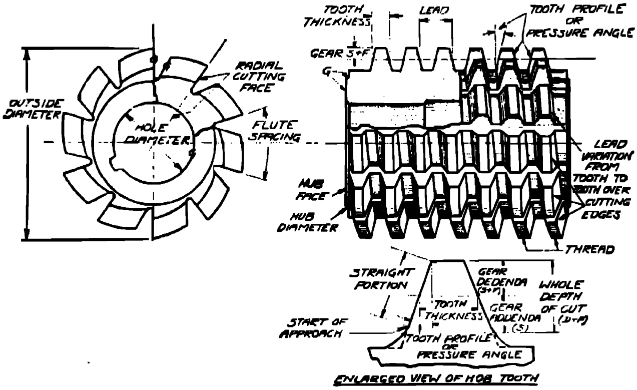


FIG. 17. A Side View of the Lees-Bradner No. 5-AC Gear-Hobbing Machine with Universal Features for a Wide Range of Work.

This shows the cutter slide and arbor support end of the work spindle. The work slide travels horizontally past the cutter head while the cutter is set to depth on the adjustable cutter head. This machine is made in two sizes to hob gears whose maximum outside diameters are 14 in. and 19 in.

Hobs are made in several shapes, namely, straight, tapered, or formed, to suit different classes of work or operating conditions. A straight hob is shown in Fig. 18, together with an enlarged view of a hob tooth. One hob of this type, of a given pitch, will cut all numbers of teeth of that pitch, either spur or helical. Right-hand hobs can be used to cut both right- and left-hand helical gears up to 30-deg helix angle. Above 30 deg, right-hand hobs are recommended for right-hand helices and left-hand hobs for left-hand helices. Hobs for gears with a helix angle greater than 35 deg should be tapered at one end to distribute the cutting over more teeth, and reduce the strain when entering the cut, Fig. 20. Tapered hobs are also used in generating worm wheels by the tangential feed method, Fig. 21.



Courtesy Illinois Tool Works.

FIG. 18. A Straight Single-Thread Involute Gear Hob Illustrating Various Features and Nomenclature.

Hobs may or may not be ground all over after hardening. Unground hobs are sufficiently accurate for the average class of work.

Courtesy Brown and Sharpe Manufacturing Co.

FIG. 19. Rough-Hobbing an Arbor Load of 10 Steel Spur Gears with an Unground Double-Thread Hob at the Rate of 17 min per Load.

Ground hobs should be specified where more than usual accuracy is required. Ground hobs for accurate work should be of the single-thread type. Multiple-thread hobs are used to obtain greater production, but they generally do not produce work as accurately as the single-thread hobs.

The cutting action on a straight hob is distributed over a considerable proportion of its length. The hob may be set up so that the teeth near one end do the cutting. When these teeth become dull, the hob is moved to a new position on its axis, so that sharp teeth engage the work. After several settings when all teeth are dull, the hob is removed and reground on the face of the teeth.

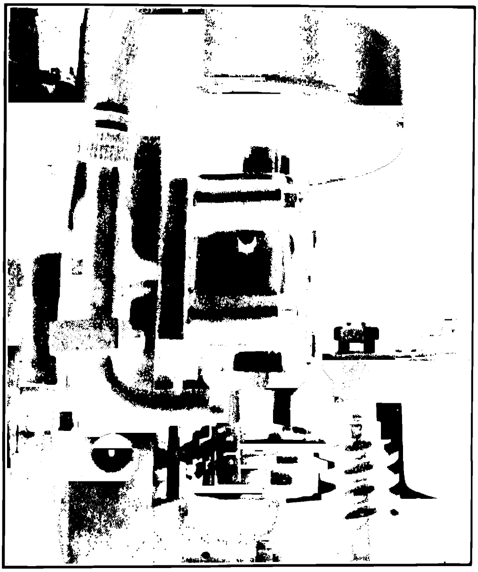


Fig. 20. Hobbing a Two-Thread Worm with a Gould and Eberhardt Tapered-Worm Generating Hob.

Examples of hobbing: In Fig. 19, **ten gears** are being rough hobbed at one pass of the hob. The figure illustrates the quantity of emulsion thrown on the cutter. There are 30 teeth in each gear of 5/8*DP*. The face width of each gear is 3/4 in. The gears are roughed with a double-thread, 3-in.-diam. unground hob of high speed steel. The hob has 12 teeth and rotates at 137 rpm, giving a cutting speed of 100 fpm. It travels 12¼ in. with a feed of 0.105 ipr of the work. The actual cutting time is 13 min with 4 min required for changing the 10 blanks. In finishing, the load consists of only **5 gears.** A single-thread ground hob of high speed steel is used with a feed of 0.068 ipr of the work. The cutting time for finishing is 20 min with 3 min required for changing the load. The setup time of the machine for roughing or finishing is 45 min.

Excellent results have been obtained by hobbing plastic gears with carbide-tipped hobs. Sintered-carbide hobs for cast iron were substituted for high speed steel to give 2,000–8 pieces per setting of hob, or 2,000–32 per sharpening (high speed steel hob had 4 settings) and 40,000 for 20 grinds of carbide hob to 480 for 15 grinds of high speed steel hob. The gear had $8DP$, 44 teeth, ⅞-in. face, and was made of micarta. The tooth shapes of the two cutters were alike. Air suction carried away abrasive dust.

FIG. 21. A Bronze Worm Wheel Is Being Hobbed on a Gould and Eberhardt No. 24-HS Machine.

Spur and helical gears to be shifted axially for engagement have their tooth ends rounded. This is done automatically as with the Peerless gear-tooth-chamfering machine, which uses a small formed-end mill to round each tooth end successively.

The hobbing of a double-thread worm of SAE 1040 steel is shown in Fig. 20. The circular pitch of the worm is 0.6667 in., 5.5 module, the face 2.519 in., and the outside diameter 2.4213 in. One worm is cut at a time with a tapered worm-generating hob 5 in. diam. with a 1¼-in. bore. The hob operates at 73 rpm and a feed of 0.010 ipr of the work. The cutting time is 11 min with an added 0.8 min for reloading. A heavy flywheel is mounted on the hob spindle to smooth the intermittent cuts.

Straight worms may be hobbed by straight hobs or by tapered hobs. The included angle between the sides of the worm teeth and between the sides of the chasing tool should be 29 deg. The width of the end of the chasing tool equals the width of the top of the tooth in the worm wheel and equals 0.31 times the linear pitch of the worm or circular pitch, *CP*, of the gear. The addendum of the worm thread equals 0.3183*CP*, and the total depth equals 0.6866*CP*, which gives the width of the top of the thread of 0.335*CP*.

A bronze **worm wheel** to mesh with a triple-thread worm is being hobbed by the radial-fed method in Fig. 21. The worm wheel has 51 teeth of 0.8147*CP* and 63.5 mm face width. It was cut with an in-feed of 0.0065 ipr of the blank with the solid shank-type, triple-thread, all-ground, 3½-in.-diam. hob rotating at 100 rpm. The mating worm had an outside diameter of 87.45 mm and a depth of thread of 0.595 in. The worm was cut by the in-feed method, feeding the hob into the blank to proper depth, after which the blank was allowed to revolve so as to clean up. The cutting time for the worm wheel was 18½ min with an added 2½ min for reloading.

For practical data and formulas for the design of worm gears, see *Product Engineering*, January, 1934, p. 2.

Relative advantages of the different types of gear cutters: From the standpoint of mathematical accuracy, the rack-shaped cutter is the best generating tool and the hob is second. The rack-shaped cutter is the easiest to make accurately, because of the plane surfaces involved. The hob comes next in order, except for possible errors in lead. The pinion-shaped cutter is difficult to make accurately because of the number of teeth which must have identical profiles uniformly spaced and concentric with the center of the cutter. Relief and rake can be provided on the rack- and pinion-shaped cutters to suit conditions, but the relief on the side of the pinion-cutter tooth introduces errors as the face of the cutter is ground. The hob has the poorest cutting action. The gashes of hobs having helix angles below 4 deg are straight, but are helical at right angles to the helix for greater angles. As far as the rate of production is concerned, the hob method is fastest. The continuous rotary motions employed in the process are ideal for speed. The pinion- and rack-shaped cutters are second. Circular form cutters, particularly of the stocking type, are designed for fast removal of metal and are, therefore, frequently used for roughing out the blank which is finished by a hob or pinion-shaped cutter.

Machines for generating spiral bevel gears: Spiral bevel and hypoid gears may be generated on the Bilgram single-point tool machine and on various generators made by the Gleason Works, the smaller sizes of which use a circular rack-tooth face mill, while the larger ones use a single-point rack-tooth tool.

The Gleason generators, Fig. 22, which produce the tooth profile of spiral bevel gears with a multiple-blade rack-shaped tooth circular cutter of the face-mill type, are built in four sizes, namely, 3, 10, 15, and 25 in. The 3-in. generator is built for both rough and finish cutting, or for completing the gear teeth of fine-pitch and narrow-face gears in one cut. The 10-in. generator is built especially for large-quantity production and is used principally for the finishing operation on gears previously roughed out on Gleason spiral roughers. The 15-in. generator adapted for spiral bevel and hypoid gears is the most universal of the generators for cutting gears and pinions in small or large quantities. The 25-in. machine is similar to the 15-in., except that it has a greater capacity. The work head in Fig. 22 is on a slide which is fed inward, forcing the blank against the cutter, whereas in the 15-in. machine the whole work head swings the blank into the cutter.

Courtesy Gleason Works.

FIG. 22. A Front View of the New Gleason No. 16 Spiral Bevel-Gear Generator Shown Set Up for Generating a Spiral Bevel Gear with a Circular Face-Type Cutter.

These generators consist essentially of a work head, a cutter saddle, and a base. The blank is fed against the rotating cutter to cut a tooth space, then withdrawn and indexed one tooth space and again fed into the cutter for cutting the next tooth space. The tooth profile is obtained through a generating action which consists of a slow relative rolling motion between the cutter in its cradle and the work spindle, corresponding to that of a gear rolling with a crown gear of which the cutter teeth represent one tooth. The crown gear in a bevel-gear system is analogous to the rack of spur gears. The various ratios of cradle roll for gears of different pitch angles are obtained through the use of change gears. Three other sets of gears are provided for change of cutter speed, feed, and index and ratio.

In the **spiral-bevel-gear tooth,** a circular curve corresponding to that of the cutter is used instead of the theoretical spiral. This makes the rapid production of the gears possible, and permits adjustments in assembly and operation.

The manufacturing operations for hypoid gears are, in general, the same as for spiral bevels for both gear and pinion. Preparation of the blanks varies only in the diameter and angles to which they are turned. The spiral angle of the hypoid tooth is usually less than that of the spiral bevel, and that of the pinion is greater. A hypoid pinion is about 20–30 per cent larger than a spiral bevel pinion. The actual cutting operations are identical, except that the hypoid pinion is cut in an off-center position.

The Gleason 40-in., 60-in., and 90-in. spiral-bevel-gear generators will generate both spiral bevel and hypoid gears and operate as shapers using a single-point tool. The tool is reciprocated in a straight slide by a simple crank drive, while the gear blank rotates continuously at a uniform rate. During one revolution of the blank, the tool makes one stroke for each tooth space. The cradle which carries the toolslide is given a slight rolling motion to produce the desired curve of the tooth across the face of the gear. These motions continue without interruptions as the tool is slowly fed to depth.

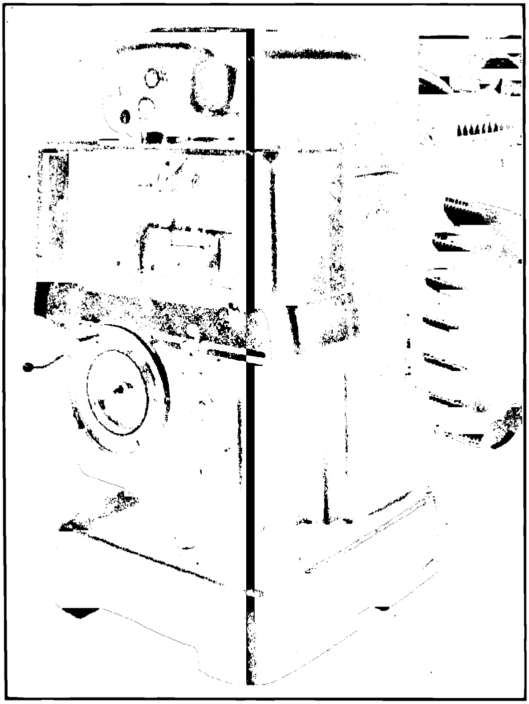
GEAR FINISHING

The silent performance of gears operating under various loads and speeds has been the goal of production engineers for years. Each year has seen progress in the development of processes and technique in this field, and the extension of refinements in manufacture to most industries using gears of all materials, sizes, and shapes.

Objectionable sound waves are produced by a very slight error in tooth contour, size, spacing, or concentricity. Suitable accuracy, bearing, and surface cannot be maintained in steel gears heat treated after machining. Gear teeth are being finished to accurate size and correct shape with suitable bearing surface and finish (1) after cutting by shaving and burnishing, and (2) after heat treating by grinding and lapping. The gears are machined leaving sufficient metal on the face of the teeth to clean up by the finishing operation.

Gear-Tooth-Shaving Machines

The gear shaver, Fig. 23, runs a circular cutting tool in mesh with the gear, producing a bright and smooth surface, correcting the tooth profile to within plus or minus 0.0001 in. of a true involute curve, and at the same time correcting tooth spacing, eccentricity, tooth bearing, and helical angle. Gears can be finished ready for the heat treating and final lapping operations in 20–40 sec each.



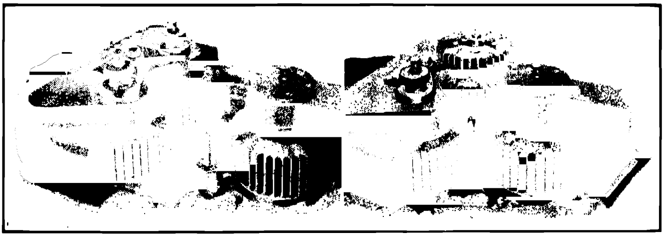
Courtesy National Broach and Machine Co.

FIG. 23. The "Red Ring" Gear Shaver Shown with a Spur Gear in Mesh with a Gashed Helical Cutting Gear.

Details of cutter teeth are shown at the right. A helical gear being shaved by a spur rack is shown at upper right.

The cutting tool itself is a helical gear of hardened steel and very accurate in shape. The teeth are gashed or slotted at one or more points along their face. The insert in Fig. 23 shows a single gashed cutter set up on the upper shaft. The cutting action is accomplished by traversing the work gear axially an amount slightly greater than the face width, while running at high speed with the cutting gear. The actual cutting is done by the sharp shaving edges at either side of the slots in the teeth of the cutting gear as the table is reciprocated longitudinally and fed vertically. The axis of the cutting gear is swiveled to provide a difference of 10–15 deg between the helix angle of the cutting tool and that of the gear. A portion of the face of the cutter is shown at the right.

A gear-finishing or shaving machine which uses a horizontally reciprocated cutting rack against which the work is forced by a hydraulically controlled head is made by the Michigan Tool Co. A straight-tooth rack-type cutter is used for finishing the teeth of helical gears, as shown at the upper right in Fig. 23. Spur gears are finished on a rack with the teeth arranged helically.



Courtesy City Machine and Tool Works.

FIG. 24. Close-Up View of the Three Burnishing Gears Used on the "Bolender" Gear-Tooth Burnishing Machine.

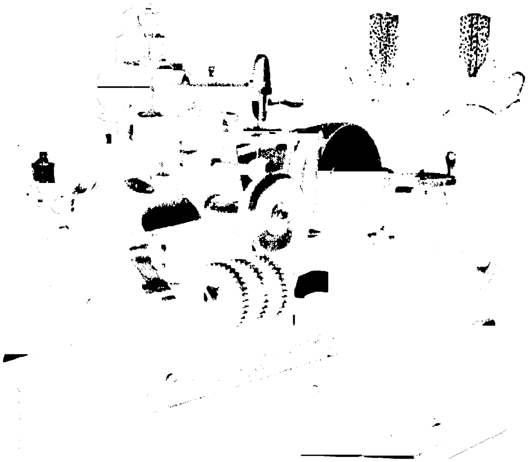
At the left the gears are separated to receive the work, and at the right the smallest spur gear of a four-gear cluster is shown loaded and compressed between the three gears for burnishing.

Gear-Tooth-Burnishing Machines

The principle for burnishing either spur or helical gears before hardening is shown in Fig. 24. The gear to be burnished and correctly formed to the pitch line is rotated under pressure between three hardened burnishing gears finished slightly oversize. The pressure ram may be operated hydraulically, pneumatically, or by weights. After the gear is loaded on the central full-floating spindle, the machine is started with the driving gear operating at 350 rpm from 3 to 25 rev, as desired, in one direction, after which it is reversed for the same number of revolutions and then stopped. The two gears on the left are mounted on the forward end of the ram and rotate freely. The single gear on the right is mounted on a fixed spindle and is the driving gear.

Gear-Tooth-Grinding Machines

The formed wheel for grinding hardened gear teeth is used on the machine, Fig. 25. These machines are made in sizes to form-grind the teeth of gears up to 72 in. diam. having a 12-in face. The abrasive wheel is formed by three diamonds mounted on the tailstock, see insert, so as to have the same form as the finished space between two adjacent teeth of the gear. The wheel-truing device has two templets six times the size of the tooth or spline to be ground, which, through a pantograph mechanism, direct and control the movements of the diamonds.



Courtesy Gear Grinding Machine Co.

FIG. 25. The Type GG-10 Form-Wheel Grinder Set Up for Grinding the Teeth of Three Spur Gears.

Gears from $\frac{1}{4}$ in. to 10 in. pitch diam., having faces up to 10 in. and from 24 to 4 diametral pitch, with any pressure angle, may be finish ground on this machine. Splines and other forms also are ground on machines of this type.

The gears to be ground are mounted between centers or on a mandrel directly connected with an indexing head located on the left end of the machine table. The table is hydraulically reciprocated so that the form wheel, located on its arbor immediately above the gears, passes between the gear teeth, which are 0.010 in. oversize, grinding both sides and the bottom of the space at each stroke. The wheel is then withdrawn, and the gear indexed one tooth. A roughing cut is first made completely around the gear, leaving the teeth about 0.001 in. over the finished size. The grinding wheel is then trued and the gear finished.

In form-grinding worms such as those used in rear-axle drives, the table reciprocates the work past the wheel as the worm is uniformly rotated. At the end of each traverse, the wheel rises and the work reverses its rotation, returns to its starting position, and indexes for the next thread. The wheel is then fed downward into position for the next traverse (*Machinery*, December, 1933, p. 241).

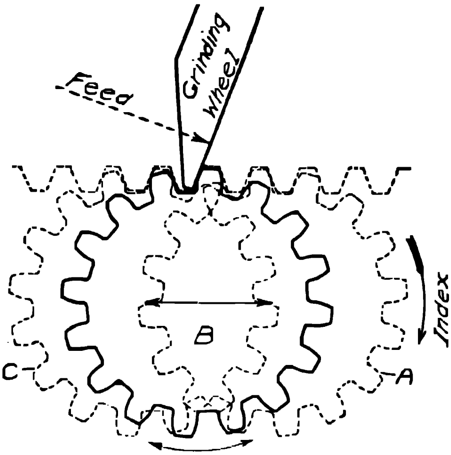


FIG. 26. The Wheel of the Lees-Bradner No. 10 Gear-Tooth Grinder Shown Operating as the Face of the Tooth of an Imaginary Rack.

True involute form teeth may be generated by the flat face of a large-diameter grinding wheel, which corresponds to one face of a tooth of an imaginary rack, as illustrated in Fig. 26. The large-diameter wheel, mounted on an inclined spindle, rotates while the gear is rolled along on its base circle in a path parallel to the rack profile as one face of the tooth is generated. The two dotted outlines of the gear, Fig. 26, show its extreme position in each direction of rolling. Starting at position *A*, the gear rolls into engagement with the grinding wheel and past it to position *C*. It then reverses and rolls back to the original position *A*, making two complete passes of the grinding wheel over the tooth face. At position *A*, the gear is automatically indexed one tooth and the grinding operation is then repeated on the next tooth. The gear is turned around on the mandrel to grind the other face of the teeth.

A change in tooth pressure angle is made by swiveling the grinding-wheel spindle. The truing of the wheel is very important and must be done accurately. The diamond with which the wheel is dressed moves in one plane only, perpendicular to the axis of the wheel. It is not moved toward the wheel as the wheel is dressed off, but rather the wheel is moved up to the diamond, thus maintaining the grinding surface of the wheel constantly in one plane. The wheel is trued or dressed, ordinarily, between gears, and not during the grinding of a gear.

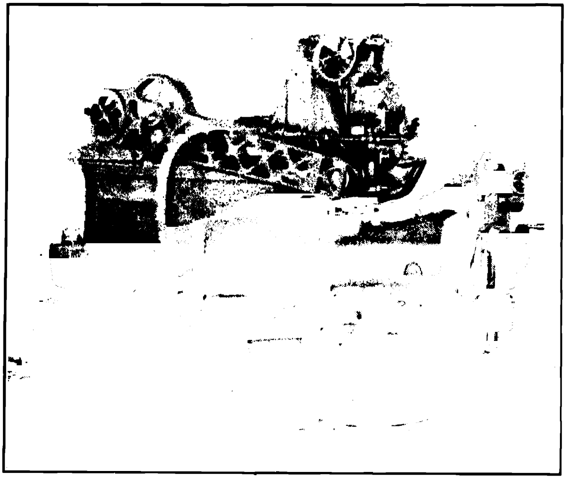


Fig. 27. The Pratt and Whitney 10-in. Hydraulic Gear Grinder for Generating Spur and Helical Gear Teeth.

The wheel is shaped to correspond with the tooth of a master rack. The belt drive to the wheel spindle is from a motor mounted on the rear end of the ram. The motor for driving the balance of the machine is located in the base.

In the Lees-Bradner double-wheel gear-tooth grinder, it is possible, by grinding simultaneously, to generate both sides of the teeth of either spur or helical gears to correct any inaccuracies arising from preliminary machining or heat treating. The rate of production is 2–2½ teeth per min on hardened gears, such as those ordinarily used in automobile transmissions.

The Pratt and Whitney gear grinder for spur and helical gears, Fig. 27, employs a wheel trued with straight sides and periphery to correspond with the shape of a tooth of a master rack. A hydraulically reciprocated horizontal ram carries the grinding wheel back and forth between two teeth as the gear is rolled sideways past the reciprocating wheel under the guidance of a master gear and rack located on the front of the rolling and indexing head, thus generating the adjacent sides of the teeth. The gear is indexed automatically, after several passes of the wheel, when it is rolled to one side. A master gear and rack, indexing racks, and ratchet wheel are required for the particular gear being ground (*Product Engineering*, August, 1936, p. 301).

Gear-Tooth-Lapping Machines

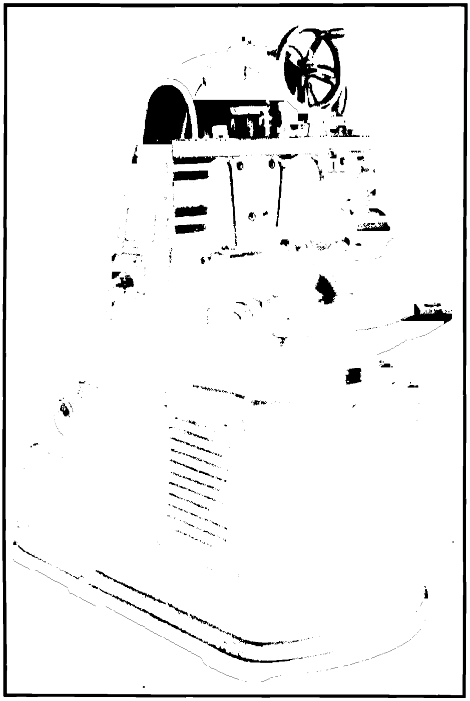
Early lapping practice consisted in running a gear and pinion together under load with a mixture of fine abrasive and oil poured on the meshing teeth. The gears had previously been machined as nearly perfect as possible and sometimes hardened. They were lapped to remove irregular surfaces or spots on the tooth face and to correct minor changes in bearing resulting from incorrect machining or distortion in hardening. Little stock was removed.

The teeth of hardened spur, helical, spiral bevel, and hypoid gears may be ground on machines, while those such as herringbone and straight bevel do not lend themselves to the grinding processes, but may be improved by lapping. Many spur and helical gears are being lapped in preference to being ground (*Iron Age*, July 6, 1933, p. 18).

To avoid the hard spots of one gear from wearing into its mate, or to equalize the abrasive action at the tooth tip with that at the pitch line, the meshing positions of the gear teeth are changed during the lapping operation so as to secure uniform lapping over the face of the teeth. A gear and pinion of complicated shape lapped in this manner are often marked and kept together in the final assembly.

The Werner machine rotates two production gears together at low speed and, at the same time, reciprocates, at frequent intervals, one gear axially and the other radially. These added motions cause the lapping to be more uniformly distributed over the face of the teeth. Other lapping machines for spur and helical gears employ a lapping gear usually made of cast iron to run with the gear.

A common practice is to mount the lap with its axis crossing that of the gear to introduce a side-sliding action between the teeth. The setup shown in Fig. 28 uses a single lap and the gear axes are crossed. The center distance between the gear and lap remains constant. The lap drives the meshing gear, which resists turning because of the constant hydraulic braking action on the work spindle, while the lapping compound is poured between them. The work is driven a given number of revolutions first in one direction and then in the other, lapping both sides of the gear teeth. This method corrects tooth contour, thickness, surface, helix, and eccentricity to tolerances within a few ten thousandths of an inch. The lapping compound consists of a fine abrasive of about 320 grain, mixed with a light oil. This abrasive cuts the lap as well as the gear. One lap will finish up to 500 gears normally, and may show an appreciable reduction in chordal thickness of the tooth but very little change in profile. Heat-treated gears about 4 in. diam. with a 1-in. face are lapped 3–5 min each.

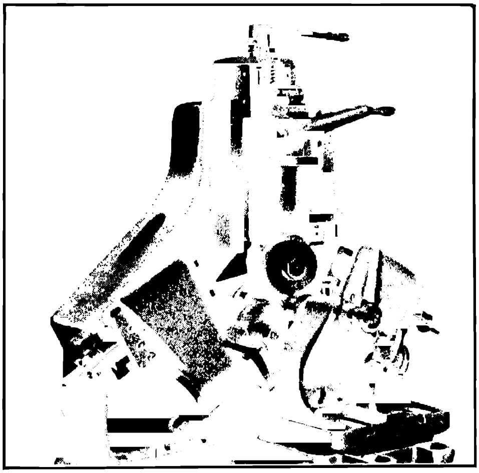


Courtesy National Broach and Machine Co.

FIG. 28. The "Red Ring" Gear-Tooth Lapping Machine for Helical and Spur Gears.

The lap shown below the gear drives the gear at high speed as the latter reciprocates to spread the lapping action across the face of the teeth.

The lapping machine, Fig. 29, has three cast-iron laps spaced equally around the work, each located on a crossed axis. It is claimed that three laps break up spacing errors and lap faster than one. Each lap has adjustable center distances and independent swiveling, and each is provided with an individual hydraulic braking action. The rotary drive is furnished through the gear which also is given a reciprocating motion as the gear and laps rotate together. This distributes the abrasive action uniformly over the face of the teeth. The timed rotation forward and reverse can be varied in ½-min intervals, namely, 2½ min on the drive side and ½ min on the back side of each tooth. The upper lap may be raised manually by a toggle joint to enable the operator to reload the machine. Gears of 10*DP* and 3-in. *PD* can be lapped on this machine at the rate of about 20 gears an hr. In most cases a set of laps will give at least 60 production hr of work.



Courtesy Michigan Tool Co.

FIG. 29. A Spur- and Helical-Gear Lapping Machine.

The gear drives the three radially adjusted and braked laps and reciprocates axially.

The Gleason machine for lapping hardened spiral bevel and hypoid gears to produce a high polish on the generated tooth surface and to correct minor changes in bearing which occur in the hardening operation is shown in Fig. 30. The gear is adjustable horizontally and vertically. The pinion is adjustable axially and horizontally. The pinion drives the gear under load, forward and reverse, with a mixture of abrasive and oil poured between them. The meshing position of the teeth is varied during the lapping operation to secure lapping all over the surfaces of the teeth. Two hardened-steel cams are used to oscillate the gear teeth across the face of the pinion as the pinion head is reciprocated in and out rapidly. Different cams are provided for lapping opposite sides of the teeth to insure the correct bearing on both drive and coast sides.

INSPECTION OF GEARS

Rigid inspection of gears is necessary to insure quiet, even running and long life. Gears may be noisy, even after passing the most rigid tests, owing to incorrect curvature of the tooth face, incorrect tooth thickness, poorly finished surface, poor bearing surface, eccentricity, incorrect center distances, or even because of the bearings or gear housing which carry the gears. Usually several devices are employed to test various elements of the gear as follows:

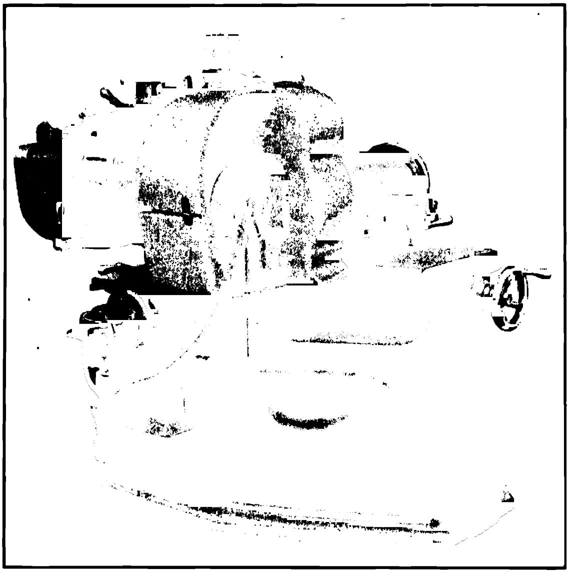
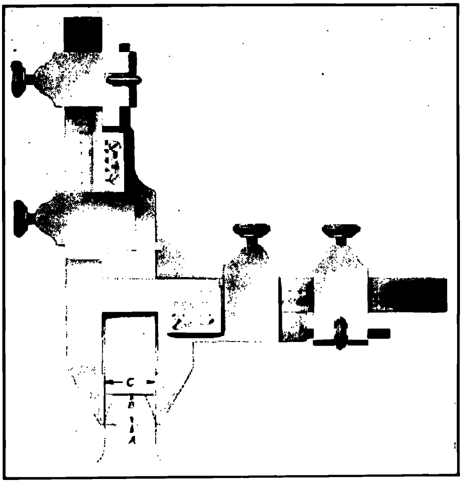


FIG. 30. The Gleason 18-in. Combination Testing and Lapping Machine for Spiral Bevel and Hypoid Gears.

1. Outside, pitch, and root diameters.
2. Tooth size, such as thickness and depth and backlash.
3. Tooth profile.
4. Tooth-to-tooth spacing.
5. Concentricity of bore and pitch circle.
6. Radial position of tooth.
7. Tooth face bearing and finish.
8. Helix angle or lead of helical gear.
9. Noise.

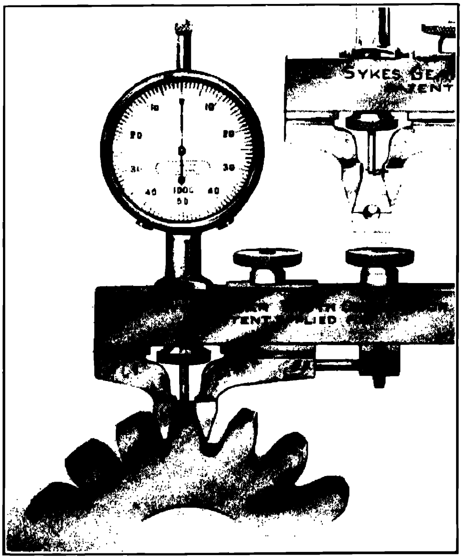
The gear-tooth Vernier caliper, Fig. 31, is used to measure the chordal thickness of the tooth at the pitch circle. The vertical scale should be set to read $B + A$, in which $A = R\ (1 - \cos \alpha)$. The horizontal scale



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 31. Gear-Tooth Vernier Caliper.

The chordal addendum ($A + B$) is measured on the vertical Vernier, and the chordal thickness (C) at the pitch circle is measured on the horizontal Vernier.



Courtesy Farrel-Birmingham Co.

FIG. 32. "Sykes" Gear-Tooth Comparator to Check the Tooth of a Gear with a Standard.

should be set to read $C = 2R \sin \alpha$. $R = PD/2$, α = the angle subtended by one-half the tooth or $CP/4$.

Measuring with micrometer calipers over **ground rolls** of a particular size placed between teeth on opposite sides of the gear is another method of measuring or comparing tooth thickness. The thinner teeth will show a shorter measurement from pin to pin (*American Machinist,* April 6, 1938, p. 275). The diameter of the rolls or wires is $1.728/DP$ for external spur and helical gears; $1.44/DP$ for internal spur and splines. The measurements over these rolls are compared to theoretical values given in tables for gears with even and odd numbers of teeth. See the Van Keuren Co. or other handbook tables.

In production work where many gear teeth are to be checked for **chordal thickness**, a **gage** or comparator is often used. The comparator, Fig. 32, is first adjusted to fit a master rack tooth, and the dial gage is set at zero, as shown in the insert. When placed on a gear tooth of the same pitch, regardless of the number of teeth in the gear, the dial should read zero for correct tooth thickness.

An **optical projection** machine for measuring and comparing objects by means of a magnified shadow is shown in Fig. 33. A hob is mounted on a mandrel between centers. By swiveling the table or swinging the bracket and adjusting the lamp house, the light beam can be thrown parallel to the helix of the hobbed tooth or screw thread, as shown. The light passes from the lamp through a pair of condensing lenses against the object, through the projection lens to a mirror in the rear from which the shadow is reflected back to the translucent screen. Any part of the image may be measured directly by the micrometer or dial gage on the carriage and the angle-measuring attachment, or it may be compared with the correct profile drawn on the screen to the enlarged scale. A 25-mm lens system will project a $\frac{5}{64}$-in. area on the screen at 200 magnifications. A $\frac{3}{4}$-in. area is projected by an 82-mm lens system at 12 magnifications. Intermediate lens systems are available. When equipped with attachments providing for vertical, lateral, and angular measurements, the machine is fully universal for measuring and comparing objects.

The Vinco dual-purpose **gear rolling inspection fixture**, with the production gear mounted on a fixed adapter at the right in mesh with a master gear at the left mounted on the swiveling arm pivoted at the rear, is shown in Fig. 34. With the gears held under light spring compression and the arm free at the front, **errors of rotation,** eccentricity, etc., are recorded on the dial indicator at the right as the gears are rotated by hand. With the arm fixed at both ends, the

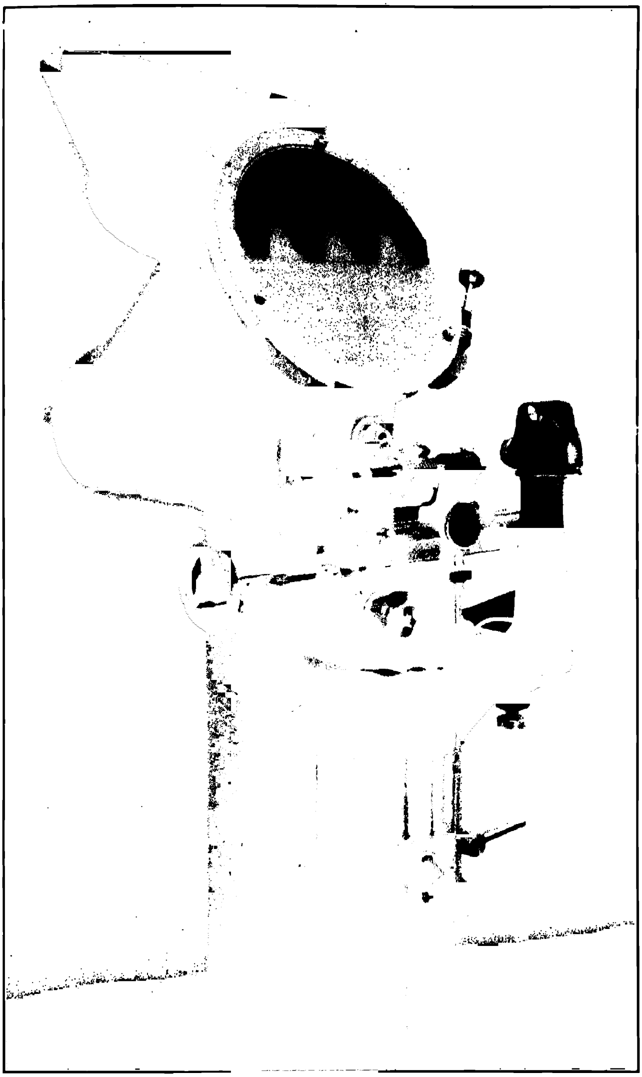


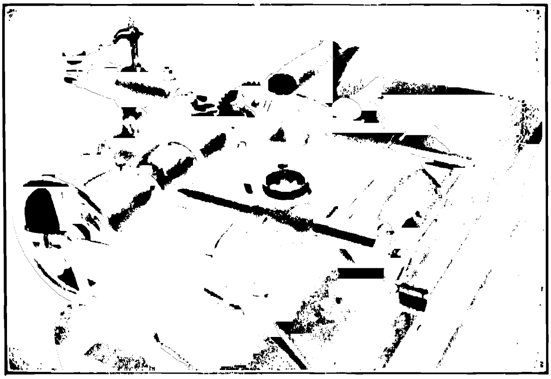
FIG. 33. The Jones and Lamson Pedestal-Type Comparator and Measuring Machine Set Up for Inspecting the Teeth of a Gear Hob.

center distance between the gears is maintained. With the work gear prevented from rotating, the back lash unit with the dial gage at the rear left is brought against the master gear and its minute rotation recorded as **back lash.**

Spur and helical gears must be checked for error in lead and helix. The machine shown in Fig. 35 does both at one setting of the gear. A master cylindrical cam comparing with that desired in the gear is locked on a shaft with the gear. A pin fits into the cam slot so that, by moving the front slide axially, the gear tooth is given a corresponding rotation. Any error of helix in the gear is detected by the two

Courtesy Vinco Corp.

FIG. 34. The Vinco Dual-Purpose Gear Rolling Inspection Fixture for Recording Eccentricity on the Front Right Indicator and Back Lash on the Rear Left Indicator.

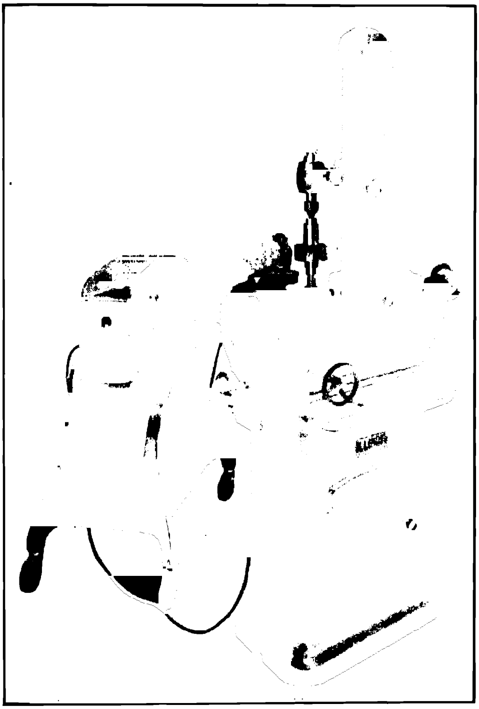


Courtesy National Broach and Machine Co.

FIG. 35. A Gear Tester for Checking the Lead of Spur or Helical Gears on the Two Front Indicators as the Front Slide is Moved along the Face of the Gear and Master Cam, and for Measuring the Helix Angle on the Rear Indicator as the Rack Tooth Is Brought between Two Gear Teeth.

dial gages at the right, which measure the deflection of the pointer in contact with the gear tooth on the pitch line.

A machine for measuring the error in **involute** of spur or helical gears is shown in Fig. 36. The work gear is mounted vertically between centers. A tracer, attached to both the Red Head unit and a dial gage, bears against the tooth face under slight pressure. As the tracer and its slide move to the right or left, the gear is rotated by means of the straight edge bearing against a base circle disk which drives the gear. This motion is such that the tracer point would trace a true involute if not deflected by an error in the tooth face. A deviation of the point from the true involute is observed on the dial gage in 0.0001 in. The same motion causes a relative position of two coated glasses in the Red Head unit which permits light from a lamp in front to pass through the glasses and bear on a photoelectric

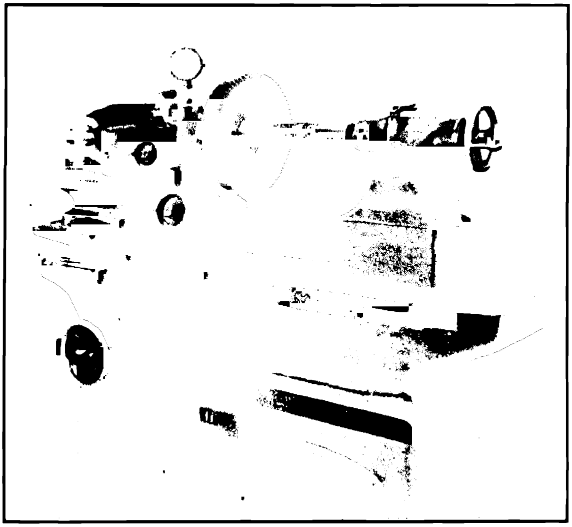


Courtesy The Illinois Tool Works.

FIG. 36. The Illinois Involute Profile Measuring Machine, Including the Red Head Recording Unit.

cell. The voltage developed is proportional to the error which is recorded on a running chart in the instrument at the left.

The Vinco involute gear checking machine employs a straight edge bearing against a segment of a circle attached to the spindle driving the work gear to be tested. The carriage on which the straight edge is mounted also has a sine bar which can be tilted to any desired angle, so that, as the carriage moves crosswise under the gear, a head, on which the tracer point and dial gage recording its motion are mounted, moves radially inward along the tooth face and upward because of the sine-bar action. In this manner the tracer point traverses a true involute. Being compressively forced against the gear tooth, its path is controlled so that any error from the true involute is recorded on the dial gage.



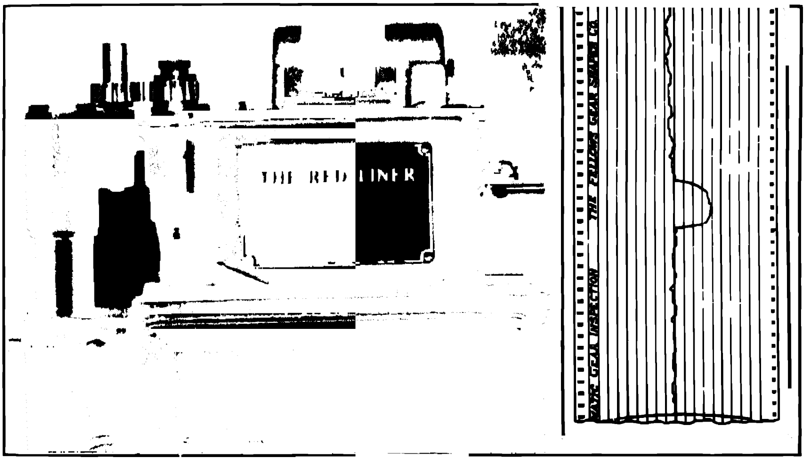
Courtesy The Illinois Tool Works.

FIG. 37. The Illinois Normal Pitch and Tooth Space Measuring Machine.

A machine for determining the **normal pitch** and **tooth space** of spur or helical gears is shown in Fig. 37. The gear, mounted between horizontal centers, is free to rotate to be indexed from tooth to tooth, as a head carrying fixed and movable points is brought against the gear teeth. The head is moved to and from the gears so that two pointers definitely locate one tooth with respect to the head, and a third pointer bears lightly against the face of another tooth and records **any error in pitch** on the dial gage shown at the top. The Red Head and recording instrument may be used in connection with this machine to chart the errors between successive teeth.

Pairs of gears of all types are often run together at varying speeds and loads so that the running action of one tooth with another, and the resulting **bearing surface** and **noise,** may be analyzed.

Spiral bevel and hypoid gears are first tested after cutting to determine the tooth bearing. They are again tested after hardening for bearing and noise. It is frequently desirable during lapping to determine the progress of the operation. The gears are run together in mesh, either with or without load, on the machine illustrated in Fig. 30. The clutch which controls the oscillating cams can be thrown into neutral to test for tooth bearing, backlash, center distance, concentricity, and noise, and then thrown back to engage either cam if further lapping is required. If only testing is required, the machine is furnished without guards, sump, cams, pump, and other parts necessary for lapping.



Courtesy Fellows Gear Shaper Co.

FIG. 38. The "Red Liner" Gear Recorder for Detecting Errors in Tooth Profile, Spacing, Thickness, Eccentricity, and Surface of Spur or Helical Gears.

The "Red Liner" gear tester, Fig. 38, **records various errors** in the gear to be tested at one setting. The gear to be tested is mounted on the fixed stud on the left, and rolls with a meshing master gear of known properties mounted on a movable stud. The motion of the movable stud as the gears are rotated together is transmitted to the pen which records the errors, amplified 200 times, on the moving chart. The deviations of the charted line from the central datum line represent the errors. The ruled lines are spaced 0.200 in. apart so that the space between represents 0.001 in. This machine records errors such as eccentricity, tooth-to-tooth spacing, and tooth shape, in combination, but in such a way that they can be separated and the amount of each definitely determined. The fixed stud carrying the production gear is adjustable vertically and eccentrically to accommodate single gears of different diameters tested in quantities, or gears of different diameters in a cluster. The machine may be hand or motor operated until the gear to be tested makes one complete revolution.

The chart at the right, Fig. 38, shows, ending at the bottom, the last half of the record of a test. Eccentricity is obvious from the runout of the line at the top. The "bump" was made by placing a piece of paper between the meshing teeth. The chart shows the gear with thick and thin teeth or variations in tooth spacing and surface roughness.

PRODUCTION OF GEARS

Operations Required to Manufacture an Accurate Helical Gear

A helical gear of 10-in. O.D. and 1¼-in. face for the camshaft of a Diesel engine is made having 72 teeth of 20-deg pressure angle, a normal pitch of 8, and a pitch diameter of 9.750 in. The gear blank is made of a forging of SAE 3250 steel. The total depth of the tooth is 0.271 in.; the addendum is 0.125 in.; and the dedendum is 0.146 in. It is to run with a gear having 36 teeth at 7.3125 in. center distance. The right-hand helix angle of the gear is 22 deg 37 min and 11 sec, giving a lead of 73.512 in.

The operations on the gear are as follows:

1. Rough-machine on all finished surfaces.
2. Normalize to relieve strains.
3. Finish-machine all surfaces.
4. Rough-hob the teeth, leaving them 0.002–0.003 in. oversize.
5. Finish-shave the teeth.
6. Harden the gear to a Rockwell "C" hardness of 48-52. The gear is held in a die while being quenched to keep distortion at a minimum.
7. Grind the counterbore and faces.
8. Lap the gear teeth on the gear-lapping machine. Between 0.0005 and 0.0015 in. is allowed for lapping. The gear is lapped to the following tolerances: the involute plus 0.0004 in. and minus 0.0000 in., index tooth to tooth plus and minus 0.0003 in., accumulated error in index plus or minus 0.0015 in., eccentricity less than 0.00075 in., error in helix angle in 6 in. plus or minus 0.001 in., wabble of teeth less than 0.001 in., backlash plus 0.0010 in., and minus 0.00075 in.

QUESTIONS

1. How may gears be defined?
2. What two forms of tooth curves are used?

3. What are the four American Standards involute tooth forms?

4. Name two or three commercial systems replaced by these standards.

5. What is the base circle? State how it is obtained from the pitch circle.

6. How are gears classified according to general shape?

7. What are the four methods used to produce gears?

8. What relation does the material of which a gear is made have to the use of the gear?

9. What are the three basic methods employed on gear-cutting machines to produce the teeth of gears?

10. What are the advantages of helical gears over spur gears?

11. Compute the pitch diameter, addendum, dedendum, clearance, total depth of tooth, outside diameter, root diameter, and base-circle diameter of an 8-pitch spur gear having 24 teeth of the composite tooth form. Select the form cutter to be used to mill the teeth.

12. Explain the difference in circular pitch of a hobbed helical gear and one cut with a Fellows helical cutter.

13. Determine the number of the form cutter which should be used to mill the teeth of a helical gear having 24 teeth of 8 pitch and a helix angle of 23 deg.

14. Using the above problem, determine the circular pitch and the normal circular pitch of the gear teeth, as well as the pitch diameter of the gear and the lead of the helix.

15. Make computations for the gear of problems 13 and 14 as cut with a full-depth Fellows helical cutter.

16. State several different ways by which the teeth of a spur gear may be generated.

17. Compare the merits of the rack-type, pinion-type, and hob-type gear-generating cutters.

18. Explain the difference between a gear hob and a multiple thread milling cutter.

19. What is meant by gear finishing, and what different methods are used?

20. What elements of a gear must be inspected?

21. Name some pieces of equipment which are used for inspecting the various elements of a gear.

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CHAPTER XV

GRINDING, POLISHING, BUFFING, HONING, AND LAPPING

GRINDING

DEFINITION

Grinding, as commonly understood by the engineer, is a process of removing material to change the size or shape of the piece by the use of a solid grinding wheel. The wheel may consist of one piece or of segments of abrasive blocks built up into a solid wheel. The abrasive wheel is usually mounted on some form of machine adapted to a particular type of work. The wheel or stone consists of crushed sharp crystals known as the **abrasive,** held together by a substance known as the **bond.** Microscopic examination of the material removed when grinding metal shows that grinding is a true cutting process, as the removed material is in the form of minute, clean-cut chips similar to those removed by a metal-cutting tool.

Polishing, buffing, lapping, and honing are other methods of removing material by the use of abrasives. Wheels and abrasives used are developed specially for each process, as described separately below. Metallurgical processes have improved along with grinding practice which has made it possible to finish to final size and shape a steel piece after it has been hardened. A few thousandths of an inch of excess metal is left on all surfaces to be finished, to be ground off after the piece has been hardened properly. This excess metal not only permits the cleaning up of all surfaces by the grinding process, but also allows for shrinkage, expansion, or other changes in shape as a result of the heat treatment. So-called ground gears, taps, hobs, etc., have now become common commodities. Some materials, such as Stellite and sintered carbide, are too hard to be machined. They are cast to approximate size and shape and finished by grinding. Rough grinding has, in many instances, replaced rough-cutting operations with steel tools, and many parts are machined completely by grinding processes.

ABRASIVES

Abrasives or cutting crystals may be divided into two general groups: natural and manufactured.

Natural Abrasives

Sandstone or solid quartz is one of the natural abrasive stones from which grindstones and whetstones are shaped. The quartz or cutting agent is relatively soft, however, so that materials harder than quartz cannot be abraded or ground rapidly.

Emery and **Corundum** are both natural minerals, obtainable in commercial quantities, having a greater hardness and better abrasive action than quartz. Both consist of very small variable-sized crystals of aluminum oxide (Al_2O_3). Emery contains considerable iron oxide and other impurities which have a diluting action. Corundum also usually is associated with impurities in varying amounts, which makes its abrasive action variable and unreliable in modern manufacturing. Manufactured grinding wheels first were made by bonding the abrasive grains of these natural minerals together by means of ceramic or pottery processes. As a result of the impurities in and the nonuniformity of these natural abrasives, they have been replaced by those made artificially, which have greater hardness, larger crystals, and more uniformity. **Diamonds** are used both for making up abrasive wheels and as a powder for lapping. Additional natural abrasives are used in connection with buffing and lapping as discussed below.

Manufactured Abrasives

Silicon carbide (SiC) is manufactured as an abrasive from 56 parts of silica sand, 34 parts of petroleum coke, 2 parts of salt, and 12 parts of sawdust in large electric furnaces of the resistance type by the Carborundum Co. at Niagara Falls, the Norton Co. at Chippewa, Ontario, and many other companies in this and other countries.

Each furnace is about 50 ft long and 8–10 ft wide. The charge is arranged in a long pile connecting the electrodes at each end. It is covered with sand and heated to about 4,000° F by about 1,500 kw per hr. At the end of 36 hr the charge is changed to solid masses of crystals which are broken up, graded, and crushed into grains.

Aluminum oxide crystals (Al_2O_3) are manufactured in the arc-type electric furnace by the fusion of mineral bauxite, a hydrated aluminum oxide clay containing silica, iron oxide, titanium oxide, etc., mixed with ground coke and iron borings. This aluminum oxide, when crushed, gives very satisfactory service as an abrasive. The cylindrical furnace consists of a steel shell about 7½ ft diam. and 6 ft high, the bottom being lined with carbon. The sides of the shell are water cooled and require no lining. The electrodes are suspended vertically into the furnace through the open top, and as the mixture is fed in and fused, the abrasive ingot is built up. When the furnace is filled, the ingot is allowed to cool. It is then cleaned, crushed, and screened.

The value of an abrasive depends upon its purity, hardness, toughness, and sharpness of fracture. For **aluminum oxide**, the electric furnace and mixture of raw materials can be regulated to some extent to control these elements, referred to as **temper**, so that an abrasive can be produced that is best adapted to the various classes of grinding and polishing.

The Norton Co. produces several varieties of **aluminum oxide** abrasive which are known as Regular, No. 38, No. 32, No. 57, No. 15, all the aluminum oxide type which are designated as A in an ASA standard, and No. 39 of silicon carbide type designated by C. The Carborundum Co., on the other hand, has two principal varieties of aluminum oxide: its regular for general work, and type AA for special purposes such as cutter grinding and toolroom work. This company also manufactures the silicon carbide types of abrasives. The Norton Co. regular aluminum oxide is the toughest and well adapted for heavy-duty snagging of steel castings and crankshaft bearing grinding and cylindrical work of all but the hardest steels. The 38 Alundum is a 99 per cent pure aluminum oxide and gives excellent service for the lightest internal and surface grinding work and for tool and cutter sharpening. The No. 19 is made up of 50 per cent each of regular and No. 38 and is adapted for grinding almost every type of high-strength material except where toughness and sharpness of high order are required. The No. 32 Alundum abrasive is a recent development in which the crystalline form is manufactured to form and size — that is, it is not crushed and screened. It is hard, tough, fast, and free cutting and can be used widely for heavy feeds on high speed and alloy steels. Wheels of this abrasive hold form very well. The 57 Alundum abrasive is especially suited for centerless grinding production, cylindrical grinding of steel, internal grinding, and machine knife sharpening. Industry reports that it is also very good for tool and cutter grinding. Numbers 15 and 35 are special abrasives.

In the **silicon carbide** abrasives, varied properties may be obtained through selection. The green grit is used in wheels for grinding sintered carbide. Sometimes sintered carbides are rough ground with a silicon carbide wheel and then finish ground with a diamond wheel.

As both the silicon carbide and aluminum oxide abrasives can be manufactured at relatively low costs and in uniform quality, they soon replaced the natural abrasives in the grinding industry. The following are a few manufacturers, together with the trade names of their products:

Manufacturers	*Aluminum Oxide*(A)	*Silicon Carbide*(C)
Abrasive Co.	Borolon	Electrolon
American Emery Wheel Works	Corundum	Carbolite
Carborundum Co.	Aloxite	Carborundum
Macklin Co.		
Norton Co.	Alundum	Crystolon
Precision Grinding Wheel Co.	Hy-Tens	Lo-Tens
Vitrified Wheel Co.	Borofied	Carbofied

Use of manufactured abrasives: Silicon carbide, just less than the diamond in hardness, is very brittle and for this reason seems to give best results for grinding materials of low tensile strength (below 40,000 psi) such as gray iron, chilled iron, brass and bronze, aluminum and copper, marble, granite, pearl, rubber, leather, and sintered carbide.

Aluminum oxide, though slightly less hard than silicon carbide, is tougher and fractures less easily and, therefore, gives better results when grinding materials of high tensile strength (above 40,000 psi) such as carbon steels, alloy steels, high speed steels, Stellite, annealed malleable iron, wrought iron, and tough bronze.

These abrasives are made for grinding-wheel and honing-stone manufacture, polishing, lapping, and coating paper and cloth.

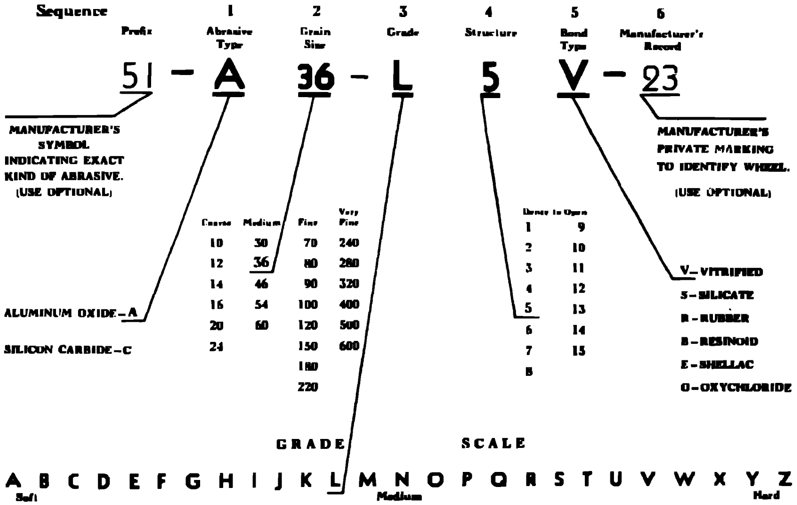
Grain of abrasives: Artificial abrasives are taken from the electric furnace in clusters and then crushed. They are then passed through a series of sieves for separating the grains into lots according to size. The abrasive is numbered according to this size so that a No. 30 grain represents the size of the particles that will just pass through a screen having 30 meshes to the linear inch, or 900 openings psi, and be retained on the screen of the next smaller size having 36 meshes per linear in. Standard grain sizes are listed in Table 1A. Often, for a particular purpose, a wheel is made up of two or even three different grain sizes. It is then called a combination grit wheel.

Bond and Bonding Processes

In order to make grinding wheels of definite shape and size, the abrasive grains are held together by an adhesive substance known as a bond. Six types of bonds, vitrified, silicate, rubber, resinoid, shellac, and oxychloride, are employed in the manufacture of abrasive wheels, Table 1A. Each process is controlled to impart distinctive characteristics to the wheels to suit all classes of grinding.

Vitrified bonding process: Vitrified wheels are bonded with a mixture of ceramic clays and porcelains. After the bond is mixed with the abrasive, the mixture is molded, dried from one to several days, shaved nearly to size, and then fused at about 2,400° F for a period of 12–14 days, either to a glass or vitrified matrix, in kilns such as are used for firing pottery. This produces an exceedingly strong wheel of a wide range of grades, Table 1A, and textures, porous but uniform, unaffected by heat or cold, water, oils, acids, etc. The size of a wheel made by this process is limited to about 36 in. diam. The vitrified bonded wheels are standard for almost three-quarters of all grinding operations. The manufacture requires about 30 days' time, which is one of its disadvantages. Other types of bonds are used only when special conditions are involved.

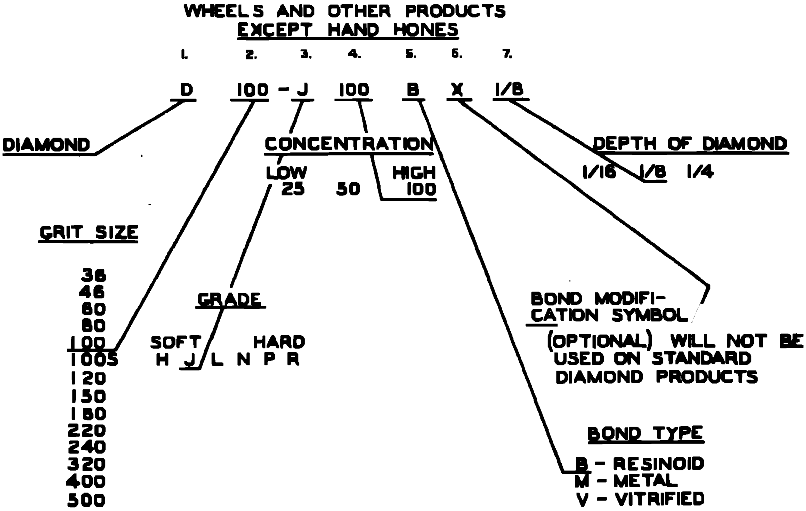
TABLE 1A. THE METHOD USED TO DESIGNATE ABRASIVE WHEELS OF ALUMINUM OXIDE AND SILICON CARBIDE ABRASIVE GRAINS



Silicate bonding process: The silicate bonding process employs silicate of soda or water glass as a principal ingredient of the bond. The mixture is tamped into a mold, which, after being dried, is subjected to a temperature of 500° F for 20–80 hr. This process is comparatively rapid, and special wheels may be made in a few days. The wheels are dependable and the baking process easily controlled. Wheels of any size up to 60 in. diam. can be made. These wheels are superior for tool, knife, and similar grinding, where only a small amount of material is removed. On account of its free-cutting action, less heat is generated, minimizing the danger of drawing the temper of the tool.

Elastic bonding process: The elastic bond consists essentially of shellac which is mixed with the abrasive grain in a steam-heated mixing machine. The material is rolled or pressed to shape and then placed in sand and baked for a few hours at a temperature of approximately 300° F. Wheels made by this process have considerable elasticity and are suitable where thin, soft wheels are required, as for cutting-off wheels for high-carbon or high speed steels without discoloration, or where a high finish is necessary, as for ball-race grinding.

TABLE 1B. THE METHOD USED TO DESIGNATE ABRASIVE WHEELS OF DIAMOND GRAINS



HAND HONES

Hand hones are marked with the grain size, bond type, and diamond depth. No grade or diamond concentration markings are shown.

Rubber bonding process: The **rubber** bond is pure rubber to which is added sulphur as a vulcanizing agent. The abrasive grain is spread between rubber sheets and thoroughly worked into the rubber by rolling between hot rolls until a wheel of the required thickness is obtained, after which it is vulcanized. Very hard and tough wheels, as thin as 0.005 in., are produced by this process. Their strength allows them to be operated up to 16,000 surface fpm, whereas vitrified wheels normally can operate only up to 6,500 fpm. These thin wheels may be used for cutting off steel tubes, formed shapes, and bars, glass tubes and tungsten rods, grinding grooves, or where severe service or a more flexible wheel is required. Thick rubber wheels also are used for snagging steel and malleable castings and as regulating wheels on centerless grinders.

Resinoid bonding process: Resinoid-bonded wheels are made up by mixing the abrasive with synthetic resin in powder form together with a liquid solvent. The mixture is then rolled or pressed to the shape desired and baked for a few hours at 400–500° F to harden the bond. Wheels bonded with synthetic resin, such as Bakelite and Redmanol, are used for purposes which require a strong, free, and fast-cutting wheel, such as high-speed, cutting-off at 16,000 fpm, and snagging wheels at 9,500 fpm, and in finishing cams and rolls which require a high finish.

The Norton Co. *Norflex* abrasive wheels and sticks are of three kinds, having fiber resinoid, resilient rubber, and cork resinoid bonds. They are used for deburring, finishing, and polishing in which only a small amount of material is removed to provide a high surface finish.

GRINDING WHEELS

Grade of Grinding Wheels

Grade represents a measure of strength of the bond or the cohesive force exercised by the bond to retain the grain in its setting. A series of grades is as important as the size of grains to meet the many requirements of practice. Wheels are graded from very soft to very hard by letters or numbers. These gradings are determined by measuring the resistance offered to a tool resembling a short screw driver as it is pressed into the wheel and twisted. The resistance is compared with that of a test wheel of known grade. A wheel which is too soft has a bond of insufficient strength to hold the cutting particles to the face of the wheel until they have become dulled; an exceedingly hard wheel has a bond which retains the abrasive too long after it has become dulled.

Recently all companies manufacturing abrasive wheels have adopted the ASA B5.17, 1949 Standard shown in Tables 1*A* and 1*B*, the former for general wheels and the latter for diamond wheels. The first number usually indicates the company's designation of abrasive, while at the end of the symbol the wheel manufacturer is at liberty to indicate his private code.

Structure

The structure or grain spacing of vitrified bonded wheels, identical in grain and grade, may differ, Fig. 1. Structure 1 of the Norton Co. has the largest number of abrasive grains and the least amount of bond per cubic inch of volume, while structure 12 represents the reverse condition, Table 1*A*. The close spacing allows the wheel to break down rapidly, thereby imparting a free-cutting action. Some types of wheels are produced in only one structure, in which case the structure number is omitted from the symbol of the wheel.

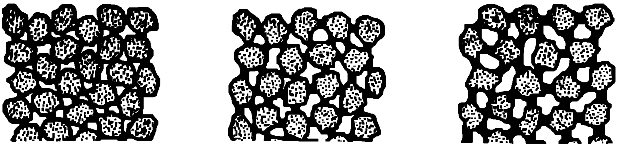


FIG. 1. The Arrangement of the Abrasive Grain and Bond in Wheels of Identical Grain Size and Grade to Produce Different Structure and Porosity.

Wheel Shapes

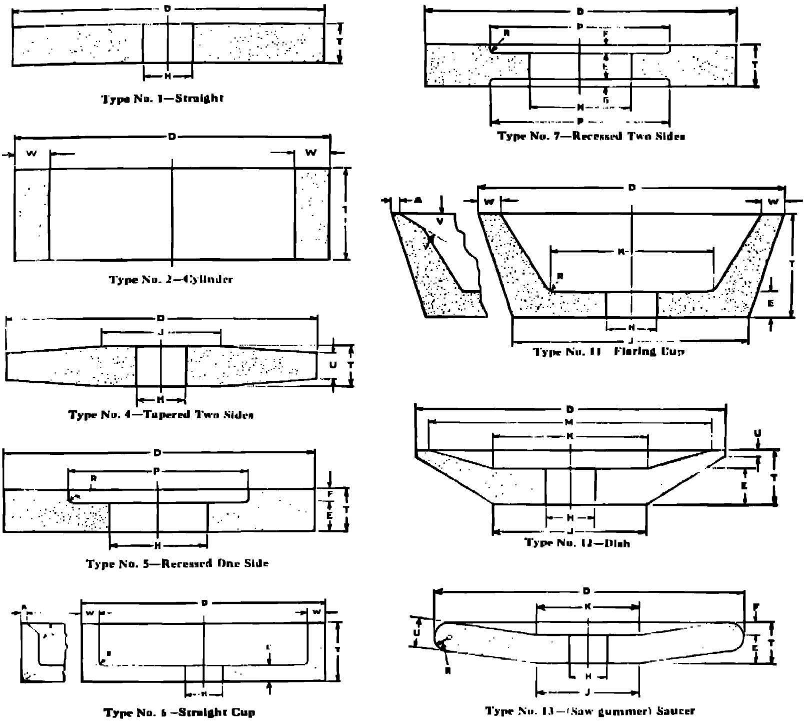
A series of nine **wheel shapes**, as covered by the Simplified Practice Recommendation, has been adopted as standard by the Grinding Wheel Manufacturers Association. They are referred to by number, Fig. 2. Each is made up in a wide variety of sizes. Three standard cones, four plugs, and three side-relieved wheels are included in the standard, but not shown.

There are twelve standard shapes of grinding **wheel faces**, Fig. 3, each shape being referred to by letter. The round and bevel-faced wheels are used generally for gumming and sharpening saws, grinding molding cutters, etc. When no shape is mentioned, type A is furnished.

Built-up wheels are used when large grinding wheels are required. Abrasive blocks are held by wedges and bolts to a metal wheel. These wheels can be made with faces up to 15 in. width and 72 in. diam. to replace the old-type sandstone wheel. Disk grinding wheels are sometimes built up by gluing an abrasive cloth to the face of a metal disk, or by holding abrasive wheels up to 3 in. thick on the metal disk by anchor bolts which engage lugs imbedded in the back face of the wheel.

Pulp stone wheels up to 67 in. diam. and 54 in. width are made up by clamping and cementing interlocked rows of abrasive segments to the periphery of a metal drum or by long bolts to the metal hub of a cemented core.

Mounted points are made in a wide variety of shapes and various abrasives for use on portable machines of either the flexible shaft, compressed air, or electrically driven type, which are being used extensively in dental work and in finishing dies, metal patterns, etc. The



Type No. 1—Straight

Type No. 7—Recessed Two Sides

Type No. 2—Cylinder

Type No. 11 Flaring Cup

Type No. 4—Tapered Two Sides

Type No. 12—Dish

Type No. 5—Recessed One Side

Type No. 6—Straight Cup

Type No. 13—(Saw gummer) Saucer

FIG. 2. Standard Shapes of Grinding Wheels. (Dept. of Commerce, "Simplified Practice Recommendations," R-45-47, July 1, 1947)

abrasive points may be fixed to the end of small steel mandrels or they may be interchangeable on the mandrels.

Designations of Grinding Wheels

Every wheel should be designated by its **size** (diameter, thickness, and bore), **shape, face, abrasive** (whether silicon carbide or aluminum oxide), **bond, grain, and grade.**

The product of each wheel manufacturer bears **markings** conforming to that company's individual standard. The Norton Co. designates a wheel as shown in Table 1*A* with the shape and face given in Figs. 2 and 3. Including bond and structure characters, the Norton Co. wheel marking for grinding steel and Stellite tools and milling cutters is illustrated as 38A46-K5VBE. This wheel is used also to point drills ½ in. diam. and larger, back off reamers, sharpen taps, surface-grind dies, and for internal grinding. The 38 represents the Norton Co. 38 abrasive, A is the ASA standard for aluminum oxide (Al_2O_3) abrasive (C would indicate silicon carbide, SiC), 46 the grain size, K the grade, 5 the structure, and VBE the vitrified bond. For offhand tool grinding, an A46–N wheel is satisfactory. This means a regular alundum abrasive of 46 grain, N grade, of regular vitrified bond. For keen finishing, a finer grain, such as 80–100, is used. Further examples are given in Table 2.

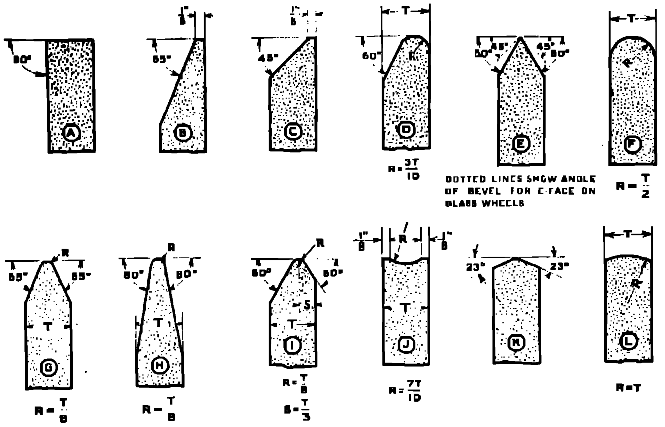


Fig. 3. Standard Shapes of Grinding-Wheel Faces.

These same wheels with perhaps a finer grain and/or a slightly softer grade would serve for surface or internal grinding.

Selection of Grinding Wheel

Care must be taken in selecting the proper abrasive, grade, grain, and bond for any job. One should acquaint himself with the literature of the manufacturer. It is often the best practice, in purchasing a wheel, to give the manufacturer a description of the job and conditions for which the wheel is intended and then let the manufacturer select the wheel. If one wheel has been used with satisfactory results, it is well to duplicate the first order by repeating the wheel specifications recorded on a tag furnished with each wheel.

Many factors have a bearing on the proper wheel selection, such as the material to be ground, whether hard, soft, heavy, or light; the accuracy and finish required; the type and condition of the grinding machine; the shape and size of the work; the nature of the grinding, such as internal, external, surface, or cutter grinding; the arc of contact, whether small or large; and whether the work is to be done wet or dry.

TABLE 2. GUIDE FOR SELECTING ABRASIVE WHEELS FOR GENERAL CYLINDRICAL GRINDING OF AVERAGE-SIZE PIECES

Symbols are those of the Norton Co.* but corresponding wheels of other companies are considered to be equivalent.†, ‡

Job or Metal	Norton Co.
Aluminum§	37C36-K5V‖
Armatures (laminated)	57A36-L5VBE¶
Brass	37C36-K5V
Bronze (soft)	37C36-K5V
Bronze (hard)	57A54-K5VBE
Cams valve (cast alloy)	A701-08B**
Cams distributor (hardened steel), rough and finish	57A80-M5VBE
Car wheels: Chilled iron	37C24-Q4B-7
Carbon steel	A20-P5VBE
Manganese steel	A16-Q8VBE
Cast iron	37C36-J5V
Chromium plating: Commercial finish	A100-J7VBE
High finish	A500-I9E
Commutators, rough and finish	37C60-M4E
Copper rolls	37C100-I9V
Crankshafts (pins and bearings), rough and finish	A54-05VA
Forgings (steel)	57A46-M5VBE
Monel metal	37C60-J8V
Nickel	37C46-M5V
Nitralloy (nitrided steel): Before nitriding	32A60-K5VBE
After nitriding	37C100-I8V
Pistons (aluminum§ alloy and cast iron): Production	37C36-L5V
Regrinding	37C46-K5V
Rubber (soft and hard)	37C24-K5B
Snagging castings: 5,000–6,500 fpm	A20-05VBE
7,000–9,500 fpm	A14-05B5
Steel (carbon, alloy, and high speed): Hardened	32A60-L5VBE
Soft	57A54-N5VBE
Steel (stainless)	37C46-M5V
Stellite	32A60-K5VBE
Tools, lathe, shaper, planer (Stellite, high speed, and carbon steel): Roughing	A36-05VBE
Finish	A60-N5VBE
Extra finish	37C-320J8E
(Sintered carbide): Roughing	39C-60IV
Finish	39C-100HV
Tools, drills (carbon and high speed steel): Shanks	A54-N5VBE
Pointing	38A46-K5VBE
Tools, milling cutters (high speed steel)	38A46-K5VBE
(Sintered carbide): Roughing	39C80-J7V, or 39C100-H7V
Finish	D100 to 150L100B
Grinding chip breakers	D100 to 150N100V

* See *Grinding Wheels*, Norton Co., and other Norton Co. literature.

† See *Gradings of Carborundum and Alorite Wheels for All Classes of Grinding*, by the Carborundum Co., and other Carborundum Co. literature.

‡ See literature of Abrasive Co. El—Electrolon (silicon carbide). Bo—Borolon (aluminum oxide).

§ It is important that a special grinding compound be selected for aluminum in order to prevent loading of the wheel face.

‖ For this wheel, C is SiC (Norton Co. No. 37) abrasive; 36 is grain size; K is grade; 5 is structure; and V is vitrified bond.

¶ 57A is Norton Co. No. 57 (Alundum) Al_2O_3 abrasive; 36 grain; L grade; 5 structure; and VBE vitrified BE bond.

** Bonds are B, V, and VBE, Vitrified; S, Silicate; R, Rubber; B, Resinoid; E, Shellac or Elastic; and O, Magnesite.

The theoretically perfect wheel is coarse enough to remove stock with sufficient rapidity, fine enough to eliminate undesirable scratches, soft enough when driven at a proper speed to allow the dulled grains to be dislodged because of increased forces incident to their own dullness, and hard enough to prevent overrapid breaking down or wearing away of the wheel.

A few **general rules** may be summarized as follows:

1. Selection of abrasive as described under *Use*.
   - (*a*) Aluminum oxide on materials of high tensile strength.
   - (*b*) Silicon carbide on materials of low tensile strength.
   - (*c*) Diamond for extremely hard materials such as sintered carbide.
2. Selection of grain.
   - (*a*) Coarse grain for fast removal of material.
     - (1) Rough grinding heavy work, Nos. 24–60.
     - (2) Tool grinding and precision work, Nos. 36–100.
   - (*b*) Fine grain for fine finish except in some machine grinding operations.
     - (1) For grinding precision parts, balls, fine-edge work, cutlery, etc., Nos. 90 and finer.
     - (2) For oilstones, glass wheels, buffing, lapping, etc., Nos. 200 and finer.
   - (*c*) Coarse grain for ductile materials.
   - (*d*) Fine grain for hard, dense, or brittle materials.
3. Selection of grade.
   - (*a*) Harder wheels on soft materials, small area or arc of contact, high work speed, safety on machines which vibrate, and for production work.
   - (*b*) Softer wheels for high wheel speeds, and when used by skilled operator.
4. Selection of bond.
   - (*a*) Vitrified bond for most general work at speeds under 6,500 sfpm, and rubber or resinoid wheels at higher speeds.
   - (*b*) Silicate bond for wheels over 36 in. diam. and free cutting to replace sandstones or for small tool or cutlery grinding.
   - (*c*) Shellac or rubber bond when subjected to serious bending.
   - (*d*) Shellac, resinoid, or rubber bond for thin wheels for sawing or grooving or for the best finish.
   - (*e*) Rubber and resinoid for high-speed snagging of castings where the wheel is operated above 9,500 sfpm.

Resinoid-bonded wheels, using **diamonds** as the abrasive, are available in three grit sizes of No. 100 grain, 220 grain, and 320 grain. The 100-grain wheel is used for the rapid grinding of sintered-carbide tools; the 220-grain wheel is used for lapping operations to produce keen cutting edges on carbide tools in a minimum time; and the 320-grain wheel is used for lapping where highly finished surfaces and very keen cutting edges are desired. Diamonds are also metal and vitrified bonded.

Proper Conditions for Grinding

Several elements are involved in the **successful use** of the wheel:

1. The wheel, its shape, size, and marking.
2. The material ground, its type, size, amount to be removed, and the desired finish.
3. The peripheral cutting speed of the wheel.
4. The type of grinding, such as cylindrical, internal, surface, or offhand.
5. Arc of contact or ratio of diameters of the wheel and work.
6. The peripheral speed of the work.
7. The cross-feed or traverse of the wheel across the work.
8. The in-feed or depth of cut.

Grinding-**wheel peripheral speeds** are specified at approximately one mile per minute for external and internal grinding in the larger hole sizes. Faster wheel speeds cause harder action of the wheel, and slower wheel speeds cause softer action. Wheels that are either too soft or driven too slowly break down and wear away rapidly. Wheels that are either too hard or driven too fast burn the work or cause the wheel face to become loaded with the material cut, or both. A soft coarse wheel with a narrow face operating under a copious supply of coolant is best on very soft metals like brass and copper.

TABLE 3. SURFACE SPEEDS IN FEET PER MINUTE FOR GRINDING AS RECOMMENDED BY THE NORTON CO.

Type of Grinding	Surface Speeds, fpm
Cylindrical grinding	5,500–6,500
Internal grinding	2,000–6,000*
Snagging, offhand grinding (vitrified wheels)	5,000–6,500
Snagging (rubber and resinoid wheels)	7,000–9,500
Surface grinding	4,000–5,600
Knife grinding	3,500–4,500
Hemming cylinders	2,100–5,000*
Wet tool grinding	5,000–6,000
Cutter grinding	5,000–6,000
Cutlery wheels	4,000–5,000
Rubber, shellac, and resinoid cutting-off wheel	9,000–16,000†

* This higher speed is recommended only where suitable bearings are employed.

† Higher speed recommended only where bearings, protection devices, and machine rigidity are adequate.

The surface speeds listed in Table 3 may be modified to suit particular conditions to get best results. Many grinding machines have but one rotating speed of the spindle so arranged that a new wheel of specified size has a surface speed slightly above, and that of the worn wheel slightly below the normal. Other machines have two or more available spindle speeds so that the rotating speed of the wheel can be increased slightly as it wears to a smaller diameter. This practice has led to the general use of more economical wheels of large bore.

In cylindrical grinding, the **work peripheral speed** produces a greater influence than a corresponding change in wheel speed. The following peripheral work speeds are recommended:

Steel shafts	50– 55 sfpm
Hard-steel rolls	80– 85 sfpm
Chilled-iron rolls	80–200 sfpm
Cast-iron automobile pistons	150–400 sfpm
Automobile crankshaft bearings	45– 50 sfpm
Automobile crankshaft pins	35– 40 sfpm

For roughing purposes, the work speed should be increased slightly so as to crowd more metal into the wheel, making the wheel function as though it were of a softer grade. In finishing, the work speed should be less to make the wheel function as though it were harder. If the wheel acts hard, increase the work speed or reduce the wheel speed. On large-diameter work, the contact between the wheel and work is larger and, therefore, the surface speed of the work should be higher than when the diameter of the work is small.

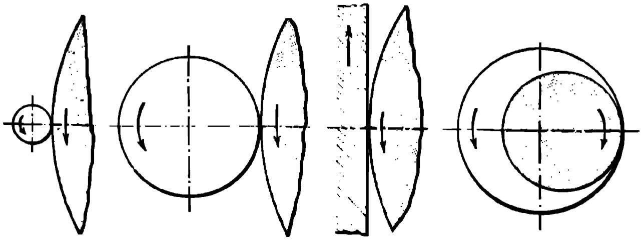


FIG. 4. The Arc of Contact between the Work and Grinding Wheel for Several Conditions of Grinding.

The arc of contact gradually increases from left to right in the four illustrations, which represent cylindrical-grinding small-diameter work, cylindrical-grinding large-diameter work, surface grinding, and internal grinding.

The grade of a wheel is dependent on the type of grinding because of the **arc of contact** involved, as shown in Fig. 4. The wheel would react as one of harder grade in each of the successive operations from left to right as the arc of contact is increased. As the contact between the wheel and work becomes greater, a softer wheel should be selected.

In rotary surface grinding with a cup wheel, Fig. 37, considerably more wheel surface is in contact with the work during the cutting than in cylindrical grinding. For this purpose a very soft bond and coarser-grained wheel is used. Similarly, in surface or face grinding, a small or narrow contact between work and wheel requires a harder wheel than for large area of contact.

For rough grinding, the **traverse** of the work or wheel should be greater than for finishing, even up to the width of the wheel face per revolution of the work. The narrower the face of the wheel, the slower should be the traverse and the faster the work revolution, both when roughing and when finishing.

Safety of Wheels

Safety in connection with the use of abrasive wheels is of great importance because of the high peripheral speeds involved. The American Standards Association has approved a safety code which has been adopted by the grinding-wheel manufacturers of the United States and Canada.

Care should be exercised in **mounting** abrasive wheels. They should be supported on the spindle with as close a fit as possible, using bushings if necessary. The outer rim of flanges or collars should bear against the wheel. A soft paper or thin rubber should be inserted between the flange and wheel so as to provide a uniform bearing pressure. The inner flange should be secured to the spindle, and the wheel should **rotate true** relative to its surface, and be in **balance** on the shaft. All wheels are tested at the factory for speed to make sure that they will operate safely at speeds considerably higher than those of normal operation. A wheel should have a bell-like ring when struck to indicate that it is solid and free from cracks.

In every case, an abrasive wheel should be well **guarded** so as to prevent accidents from flying particles as well as parts of a broken wheel. As far as service permits, hoods should cover the wheel, and in no case should the maximum wheel exposure be greater than 180 deg. **Work rests** should be rigid and located within ⅛ in. from the wheel face to prevent work from being caught between the rest and wheel.

Dressing and Truing Grinding Wheels

The face of a grinding wheel should be kept sharp and clean so that newly fractured crystals are present to act as cutting tools. Wheels often become loaded with soft materials being ground or become smooth and glazed where the wheel action is too hard. The face of the wheel should be dressed or trued frequently.

The **dressing** operation consists of breaking off the dulled outer surface of the wheel, although it does not insure a true cylindrical shape or straight face. Several types of dressers are available for this purpose. Revolving metal cutters, Fig. 5, consist of stars and disks. The heel is hooked over the front edge of the work rest, or a straightedge temporarily doweled to the face of the work rest, as shown, while being worked slowly back and forth across the face of the wheel. Abrasive bricks or sticks are sometimes rubbed across the face of the wheel to remove dull abrasives. The Metcalf small abrasive wheel rotating freely on a spindle with handles at each end is forced against the face of the grinding wheel at crossed axes and traversed slowly four or five times with an in-feed of 0.002 in. for rough work to 0.0005 in. for fine finishes. Sometimes abrasive wheels, operated at high speed by a small electric motor, are held against the wheel to be dressed. Long thin tubes filled with bonded abrasive, as the Diamo-Carbo, also are made for hand or machine use in the dressing of wheels. The abrasive extending slightly beyond the tube is pressed against the wheel to break off the dulled grains.

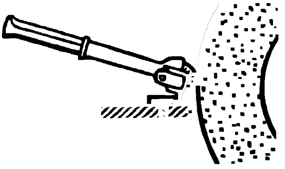


Fig. 5. A Hand-Operated Revolving-Metal-Cutter-Type Wheel Dresser in Operating Position.

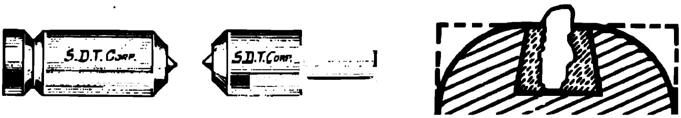


Fig. 6. Two Types of Diamond Nibs Furnished by the Standard Diamond Tool Corp. and a Method of Mounting the Diamond.

Dressers are sometimes used on large wheels for precision work, but only when they are clamped rigidly to the machine.

Truing is usually accomplished by means of a diamond-pointed tool. The diamond is imbedded in the end of a soft-steel rod or nib, Fig. 6. The rod is held rigidly in a holder on the work carriage of the machine and should point 10–15 deg below the center of the wheel, Fig. 7. The diamond is slowly traversed across the wheel face, taking a very light cut of 0.001 in. or less per pass under a copious supply of coolant. The size of the diamond should be in proportion to that of the wheel on which it is to be used. A $\frac{3}{8}$-carat diamond is recommended for use on a wheel 4 in. diam. by $\frac{1}{4}$-in. face, while a 1-carat diamond is recommended for a 12-in. diam. wheel with a 1-in. face.

The Carboloy Co. truing tool used for finish dressing wheels has a point consisting of many small diamonds firmly imbedded in sintered carbide. In use, the rod is rotated 90 deg periodically and can be used up entirely.

Grinding with **crush-trued wheels** is now becoming general practice for grinding threads and intricate contours. Crush dressing or truing is a process of shaping an abrasive wheel face with a steel roll, either hardened or soft. This practice is applicable to all types of grinding operations. Forms or contours produced on the wheel face can be transferred to the workpiece during a plunge grinding operation. The crush dresser, Fig. 8, made in a convenient size up to 4 or 5 in. in diam., is fed against the grinding wheel with pressures varying from 100 to 500 lb per in. of wheel width. This naturally requires strong, rigid material. Crusher rolls are often made of hardened, high speed steel. They are carefully ground to the exact profile desired on the finished work, and they operate against the wheel at 150–300 fpm. Surface finishes of 20–25 microinches, r.m.s., are common. Grinding oil, such as a blended sulphurized mineral oil, prevents the wheel from chipping during the crush truing, and it is also more satisfactory than emulsions when grinding precision surfaces, as it reduces the crusher wear, keeps the wheel face clear, helps maintain the wheel form, and promotes a high surface quality.

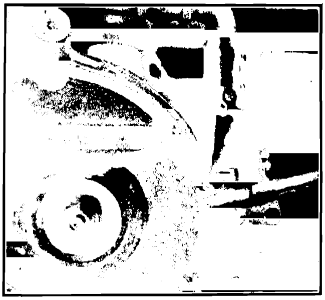


FIG. 7. Diamond Nib Supported in a Holder on the Tailstock Center of a Cylindrical Grinder for Truing Abrasive Wheels.

POLISHING

Definition

Polishing is the operation by which coarse scratches or toolmarks, or rough surfaces left after forging, drawing, rolling, etc., are removed with a polishing wheel. The abrasive grains are set up with glue or thermosetting resins on the face of the polishing wheel which has more or less flexibility. Manufactured grains for polishing are given an acid etch to roughen the surface and thus increase the holding action of the glue.

Polishing may be divided into **three steps** which are known as rough polishing, dry fining, and finishing or oiling. The abrasive grain used for roughing usually runs from Nos. 20 to 80, for dry fining from Nos. 90 to 120, and for finishing or oiling from No. 120 to the fine flours. For the first two steps, roughing out and dry fining, abrasive-coated polishing wheels are generally used dry. For finishing or oiling, wheels worn down a little are then coated with stearic acid, tallow, oil, beeswax, or manufactured greases to lubricate and prevent overheating and loading. Wheels coated with the finer emery work well with grease. Additional abrasive mixed with hard grease is often added periodically to the face of the wheel to give a better finish, so this step is partly polishing and partly buffing.

Courtesy Norton Co.

FIG. 8. A Roller Crusher Mounted in a Rigid Support Still in Position after Crush Truing the Face of the Wheel in a Cylindrical Grinder.

At the bottom the workpiece is shown after being ground with the crush-trued wheel.

To prepare a rough forging for plating might require all three steps of polishing. The first or even second polishing step may be omitted on some smooth objects or soft materials. Many steel or nonferrous metal parts are given a high luster without being plated. The final high luster or " color " on a part before and after plating is usually obtained by a buffing operation described below under *Buffing*.

Polishing Wheels

Early wheels used for polishing consisted of **wooden disks** faced with leather and turned to fit the form of the piece to be polished. This type of wheel is still used for flat surfaces or on work where it is necessary to maintain square edges. Various other types of wheels are now in common use which provide faces of varying flexibility. The cutting action is freer and the life of the wheel is prolonged by making the wheel face flexible, although formed faces are maintained by having hard wheels.

The **compressed wheel** has a steel center, the rim of which holds the laminated material placed crosswise to form the wheel face, as shown at *B*, *C*, and *D*, Fig. 9. Leather, canvas, linen, paper, felt, rubber, etc., are used extensively for this purpose. This wheel is strong, durable, and easily kept in balance. It is a precision polishing tool and can be used for nearly every purpose. Its face can be formed to fit contour surfaces, and its cushion and density controlled. This type of wheel lasts almost indefinitely. The **compressed-canvas wheel** is used extensively in polishing cutlery, flatirons, shears, skates, golf-club heads, and automobile parts. The **compressed-leather wheel** has its field in the initial operation on flatirons, carpenter's chisels, axes, etc. The **compressed-felt wheel** is best where a high color is required, such as on small tools and surgical instruments. The **compressed-paper wheel** is adapted to rough wear. It has little flexibility and approaches the action of a grinding wheel.

Wheels are built up of **disks** of buffalo hide, sheepskin, or bullneck leather, or soft materials, such as felt, cotton, canvas, and muslin. Wheels built up of cloth disks are loose, stitched, or glued, depending on the resilience or pliability required. Walrus hide from ½ to 2 in. thick, more porous and softer than leather, is sometimes used to make small-diameter formed-face wheels. These wheels are used extensively for polishing as well as for buffing. The compress-canvas wheel replaces walrus hide in larger sizes.

The **solid canvas** polishing wheel is made up of full disks of canvas. The wheel may be constructed by gluing each disk to the next until the entire face width is formed. In an alternate method canvas disks are laid up into sections of about ¼ in. and spirally machine sewed in ¼-in. rows. The sections are then glued together to the proper width. The less glue in the wheel, the softer it will be. The different degrees of softness are obtained by varying the number of canvas disks put into each section before the sections are glued together. A flexiblized glue containing a softener, such as glycerine or eugenol, also is used to make the wheels more flexible. Iron flanges

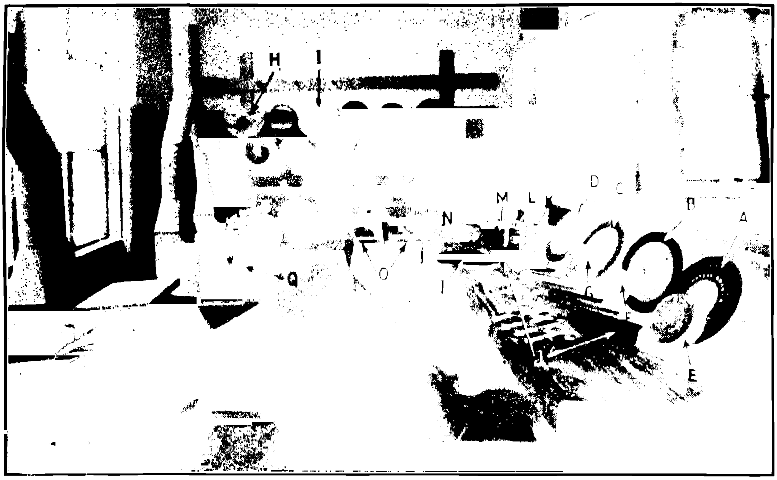


Fig. 9. The Polishing and Buffing Room of the Machine Tool Laboratory.

Two 2-wheel Cleveland Armature Works 1-hp 1,800-rpm, direct motor-driven **polishing and buffing stands** are shown with exhaust guards. The **wheels on the machine** from front to rear are, at ***P***, a No. 80 grain set up on a hard felt wheel; a No. 120 grain set up on spirally sewed canvas disks glued together; at *Q*, a No. 120 grain set-up grease wheel of glued spirally sewed canvas sections, used with No. 180 grain emery cake shown on the guard; and a full-disk buff of once-sewed sections used with Tripoli composition.

Various **polishing and buffing wheels** are shown on the bench and wall racks as follows:

A. 14-in.-diam. cloth-flex polishing wheel of glued sections of sewed pieced-buffs with glued canvas cover and 6-in. steel side plates.
B. Compress canvas polishing wheel with 2-in. cushion, medium density.
C. Compress felt polishing wheel of 2-in. cushion, medium density.
D. Compress leather polishing wheel with 2-in. cushion, medium density.
E. 8-in.-diam. polishing wheel of spirally sewed sections of cotton buffs set up with 220-grain aluminum oxide abrasive.
F. 6-in.-diam. steel wire brush wheel.
G. 8-in.-diam. Tampico brush wheel.
H. 14-in.-diam. once-sewed full-disk cotton buff sections.
I. 14-in.-diam. $^{3}/_{8}$-in. spirally sewed cotton buff sections.

A number of cakes of **cutting-down or buffing compositions** presented by the McAleer Manufacturing Co. are shown on the bench at *J* from front to back, as follows:

J. 1. No. 13 white chrome composition generally used to color chromium plate.
  2. No. 77 coloring composition for stainless steel sheet and strip.
  3. No. 94-C medium-grade greasy cutting-down composition for stainless steel sheet.
  4. No. T-95 dry-grade Tripoli for high-grade cutting-down on copper and brass.
  5. No. 180 saponifiable emery cake used for greasing.
  6. No. 9 green chrome composition for coloring chromium plate, replaced largely by levigated aluminum oxide.
  7. No. T-17 hard rubber composition.
  8. " 00 " rouge. Very dry high-grade rouge compound to color soft metals.
  9. " A " dry-grade coloring composition to color brass, copper, or aluminum.
K. Grease.
L. Lime color buffing composition in sealed can.
M. Lime color buffing composition ready for use.
N. A 4-pot water-chamber electric heater for preparing glue.
O. Two trays containing No. 80 and 120 **polishing grain** with a worn polishing wheel on a mandrel ready to be set up.

or steel plates about 4 in. smaller in diameter than the wheel are placed on each side. These plates are attached to a steel hub or are riveted together and keep the wheel shape true and the bore to correct size. The disk canvas wheel set up with the coarser abrasives is superior to any other type of wheel for roughing out work.

The **cloth-flex wheel,** made up of sections of cotton buffs, *A*, Fig. 9, is used for contour work similar in character to the disk canvas wheel, but with finer abrasives. It can be made more flexible to adapt itself to curved surfaces, such as shovels and automobile bumpers.

Eight different grades of cloth are used in the manufacture of these buffs, each grade for a particular class of work. The sections may be made up by sewing in several ways. They may be spirally sewed over the entire surface, at wide or narrow intervals, or they may have two or many rows of concentric sewing from the center out to the periphery. These buffs may be glued together in different ways, using little or much glue to give different degrees of hardness. Muslin wheels are made up in much the same manner as canvas wheels.

The **solid felt wheel** is used for polishing glass and for greasing and coloring operations where a high color is required. It has a distinct field in the polishing of formed surfaces of stainless steel.

Belts of cloth or leather often are charged with abrasive for polishing flat work, Fig. 12.

Setting up polishing wheels: By setting up is meant the gluing of the abrasive to the face of the wheel, preparing it for the polishing operation. A pound of high-quality hide glue should first be soaked until it jells in 1 lb of distilled cold water when grain sizes 20–40 are used. For finer grains, more water should be added, as 2 lb of water for 1 lb of 80–90 grain size. Not more than a 4-hr supply of fresh, clean glue should be prepared at a time. After 2 or 4 hr for ground glue or 10 hr for flaked glue, the mixture should be melted at a temperature of 135–150° F in small thermostatically controlled pots. These pots should be covered and water jacketed as shown at *N*, Fig. 9. The glue should be kept at this temperature as short a time as possible. The hot glue is applied to the face of the wheel with a brush; the wheel is then rolled in the abrasive which, for convenience, is spread in a trough 2 or 3 ft long, as shown at *O*, Fig. 9. Best results will be obtained by preheating the abrasive and wheels to 110° F. After coating the wheel with the abrasive, it should be allowed to dry at 75–90° F at a relative humidity of 40–50 per cent for at least 48 hr. Before applying the hot glue to the face of the wheel, the old glue should be washed or scraped off and the wheel should be trimmed to run true. This is often done with an old file, buff stick, piece of abrasive wheel, or on a special lathe for this purpose, while the wheel rotates at about 225 rpm, Fig. 18.

A sodium silicate cement recently has been introduced as a substitute for glue in setting up polishing wheels of coarser grains. It is cheaper than glue and not influenced by temperature and humidity when being set up.

Coated abrasives in the form of sheets, strips, rolls, belts, or disks consist of various flexible materials of paper, cloth, or the combination, paper reinforced with cloth, to which are glued abrasives of grain sizes corresponding to those used in polishing. The abrasives consist of garnet (for sanding wood), flint or quartz (for home-workshop use), emery (for metal polishing), crocus (for finish polishing soft metals). Thus we have garnet paper, flint paper (sandpaper) emery paper and cloth, crocus cloth, etc., each of a particular grain size. Silicon carbide and aluminum oxide are also used as coated abrasives. The grain size of SiC, Al_2O_3, and garnet abrasives used for this purpose are designated as mesh grain size or equivalent symbol series in parentheses as follows: 600 (12/0), 500 (11/0), 400 (10/0), 320 (9/0), 280 (8/0), 240 (7/0), 220 (6/0), 180 (5/0), 150 (4/0), 120 (3/0), 100 (2/0), 80 (1/0), 60 (1/2), 50 (1), 40 (1 1/2), 36 (2), 30 (2 1/2), 24 (3), 20 (3 1/2), 16 (4), 12 (4 1/2). The symbol series for garnet, flint, and emery differ slightly from those given above. The coating may be closed or open. In closed coating, the paper or cloth backing is covered entirely by abrasives, whereas in open coating, approximately 50 per cent of the backing is covered. Thermosetting resins, rather than glue, are often used to bond the abrasive to the belt as they are more resistant to heat and to moisture or wetting.

Speed of polishing wheels: For ordinary operations, it is good practice to employ a surface speed of about 7,500 fpm, although up to 15,000 fpm often is employed. If the speed is too low, the grain is torn from the wheel too readily. Belts should have a surface speed of 2,000–2,500 fpm.

The use of polishing wheels and abrasives is discussed after *Buffing*.

BUFFING

Definition

Buffing is a form of surface finishing in which very little material is removed. The sole purpose is to produce a surface of high luster and attractive appearance. The powdered abrasives, usually of the fine flours, are applied to the rotating face of the wheel, not by gluing but by pressing a composition containing the abrasive against the face for a few seconds. The work to be buffed is then held against the wheel. Periodically, the abrasive is replenished.

Buffing is divided into two separate operations: cutting down and coloring. **Cutting down**, usually on a sewed-disk buff, brings the surface previously rolled, stamped, tumbled, or polished to a luster. It smooths and removes metal, tending to fill in irregularities and depressions and remove high spots. **Coloring** is usually done with a soft, loose buff after the cutting-down operation to produce the highest luster. Coloring also is used to bring plated surfaces to a high luster.

Buffing Wheels

Buffing wheels are made of soft, pliable materials, such as soft leather, felt, linen, cotton, or muslin, already referred to under *Polishing Wheels*.

From 18 to 20 disks may be sewed together into sections in several ways, such as once about the hole (loose), spiral, concentric, radial, and at right angles. The buffs are sometimes made up of plain disks as shown at *H*, Fig. 9, and sometimes of material which is folded or plaited. Sewed piece disks are those made up of small remnants. Cloth of which disks are made is specified according to the number of yards of a given width per pound. Thus, 88 × 96, 3.20 × 40, means that there are 88 threads per in. running the short way or woof of the cloth, and 96 the long way or warp of the cloth, and that there are 3.20 yd of 40-in. cloth to the pound.

The hard, closely woven buffs, such as 88 × 96 thread count, are usually used for cutting down plated wear before plating when a coarse abrasive, such as emery or Tripoli cake, is used. Medium-weave buffs, such as 64 × 68 or 80 × 84 thread count, can be used for both cutting down and coloring. For final coloring, only the soft buff, closely woven of a low thread count, as 48 × 48, 2.50 × 40, is used. The loose buffs, Fig. 12, are better for irregular surfaces as they adapt themselves to the work. They can be operated at higher speeds than the sewed buffs or polishing wheels.

Tampico fiber brushes, *G*, Fig. 9, are used for buffing operations, as are wire brushes made with coarse brass or German silver wire, to give a satin finish to nonferrous metal parts. Steel wire brushes, *F*, Fig. 9, are sometimes used for buffing, but more often for cleaning operations. Bristle or wire wheel brushes with a grease composition containing sharp abrasives are used on deep-grooved ornamental parts.

Buffing Speeds

Buffing is accomplished at speeds higher than those used in polishing. From 8,000 to 17,000 sfpm are used, depending on the type of wheel and the nature of the work. Brushing is done at 3,000–6,000 fpm with Tampico and emery cake before buffing at 6,000 fpm.

Buffing Abrasives

For buffing purposes many kinds of abrasives are used. The common ones, in order of hardness, toughness, and sharpness, are aluminum oxide, green chromium oxide, emery, crystalline silica, Tripoli, pumice, amorphous silica, crocus, lime, and rouge. Other materials, such as rotten stone, whiting, tin oxide, and cuttlefish bone, are sometimes used for final buffing in specific instances.

Fine aluminum oxides are more often used on white chromium and stainless steels. A dry composition for chromium plate or stainless steels contains from 80 to 87 per cent abrasive, a medium grade runs from 72 to 80 per cent abrasive, and the greasy grade contains less abrasive.

Emery consists chiefly of natural aluminum oxide which is sharp and hard for cutting, and magnetic iron oxide which is softer for polishing. It is available in various grain sizes and is fast cutting.

Tripoli powder, first found in Tripoli, Africa, is a decomposed rock very high in silica or silicon dioxide. It has grains different from crystalline or amorphous silica in that they are soft, porous, and spongy in appearance. These grains are free from sharp crystalline edges. In use they crush and continuously present fresh surfaces. This is one of the most important abrasives used in buffing compositions. The grains are tough enough to cut down and remove minor pits, mars, and scratches, and at the same time produce a beautiful, smooth finish. Tripoli works rapidly on all softer materials such as brass, copper, and aluminum, and will complete an average job in one operation. It is the one all-round polishing agent used for the widest variety of purposes.

Once-ground Rose Tripoli from the Seneca, Missouri, deposit is generally used. It is made into three grades: dry-grade Tripoli, containing from 69 to 72 per cent Tripoli; medium, containing from 66 to 69 per cent abrasive; and greasy, containing a lower percentage of Tripoli in a greasy binder. The greasy composition is usually used on large parts and on sheet brass or copper. The dry grade is used for smaller parts on which a high color and minimum grease layer are desired as on copper or brass before nickel or chromium plating.

Crocus is a ferrous oxide red in color and rather hard in structure. Crocus compositions in stick form are used extensively for buffing steel cutlery and other iron or steel surfaces requiring a high finish.

Rouge, a red amorphous powder consisting of ferric oxide, is softer than crocus. Dry compositions containing up to 90 per cent of the finely crushed powder are used for the most delicate finishing operations, such as preparing metallographic specimens for microscopic inspection and also for buffing gems, gold, silver, platinum, glass, brass, nickel, steel, and hard rubber. A **white rouge** which contains a high percentage of aluminum oxide and **green rouge** containing green chromium oxide and silica are now replacing rouge in large manufacture.

Pumice, a cellular spongy ground volcanic lava, is used on hard rubber, celluloid, glass, etc., and on brass to produce a brushed effect. Noncrystalline or **amorphous silica** has rounded hard grains, free from sharp cutting edges. It is the principal ingredient of so-called coloring compositions which give a beautiful luster to properly prepared surfaces. It has a low cutting property and is, therefore, usually preceded by Tripoli composition.

Lime, as used in lime compositions, is freshly calcined limestone high in magnesia, consisting chiefly of oxides of calcium and magnesium. The grains are softer than amorphous silica, but similiar in structure and properties. Lime compositions slack rapidly on exposure to air and, therefore, are poured into tin containers, hermetically sealed, and opened only when needed for use. They are the universally accepted standard for color buffing to bring out a luster of the highest type on solid or plated nickel, brass, copper, or even steel. Lime compositions are sold as White Rose, Fast Finish, etc., in various degrees of greasiness. Extra dry, containing 78 per cent lime, is used for softer nickel, slow or medium buff speeds, and small parts of brass or steel. Medium dry, containing up to 75 per cent lime, is used for harder nickel, faster speeds, and for nickel on steel. That with 72–65 per cent lime and most lubrication is used for the highest-speed work and for the hardest nickel, as well as on large steel parts, such as bumpers and radiators. Nickel-plated work is colored only with lime composition.

Powdered **cuttlefish bone** is used extensively in a coarse and fine powdered condition to rough and finish silicate and porcelain fillings used in dental work. In dry buffing metals, such as fillings in dental work, fine emery is first used followed by finely powdered cuttlefish bone, after which the fillings are finished with rouge. An agate burnishing stone also may be used to give a final luster and hard surface.

Buffing Compositions

For use in buffing, the abrasives mentioned above are usually mixed into **compositions** consisting of various oils, fats, greases, and waxes so that they may be applied readily and periodically to the face of the buffing wheel. Water-soluble soaps, casein, or glue binders are used to insure absolute removal of grease, like buffing copper before chromium plating. These compositions and abrasives are usually formed into cylindrical sticks or into brick-shaped cakes. They must be sufficiently hard, tough, and strong under ordinary temperatures to avoid breakage and crumbling, and at the same time must have a softening or melting point low enough to permit the transfer of the right amount of material to the wheel when heated by friction of contact. They should not glaze the surface of the wheel, and they should contain fully saponifiable grease which will be removed from the work when it is passed through commercial cleaning solutions. These greases usually consist of **stearic acid,** a white crystalline organic acid, beeswax, and tallow for grease and sometimes a small amount of soap. Paraffin wax, petrolatum, and vegetable waxes are used also in greases. They are mixed to give the properties required for different types of finishes.

Greaseless compositions which contain a special glue, glue preservative, and added agent to raise the softening point, are now being used as a substitute for free grease. These compounds, containing natural or artificial abrasives as required, frequently eliminate grease polishing operations, cutting-down buff, and washing and drying. They also may eliminate polishing-wheel operations with the finer abrasives, particularly on work having sharp contours or ornamentations where a soft pliable wheel with an abrasive-coated surface is desirable. They are particularly suitable for cutting soft metals, and for producing a satin or butler finish.

Examples of Polishing and Buffing Practice

The grain size and type, composition, type and hardness of wheel, pressure of work against the wheel, and speed of wheel all must be considered and adjusted to give best results.

Sheet aluminum, brass, copper, zinc, and die-casting materials usually require only the cutting-down and color-buffing operations before plating. If marks are too deep to be removed with a buff or if there is a flash left by the parting line of the die, a dry-fining or greasing operation is advisable. These softer metals all color to a high luster.

Aluminum canopies and shells for lamps, stamped or spun from sheet, are given a final satin finish as follows:

1. Grease with 120 aluminum oxide polishing grain set up on a spirally sewed wheel of $^{84}/_{92}$ unbleached cotton fabric at 6.000 fpm.

2. Grease with 180 grain on a spirally sewed wheel of $^{64}/_{68}$ unbleached sheeting.

(For a faster and cheaper job, operations 1 and 2 often are replaced by a single dry-fining operation using a 120-grain abrasive.)

3. Cut down with a greasy Tripoli composition on a spirally sewed cotton wheel at 8,500 fpm.
4. Pumice and water on a Tampico wheel at 4,000 fpm.
5. Clean, dry, and lacquer.

Another method consists of but two operations as follows:

1. Use Lea compound grade N on a 10-in. pocketed-type buff at 1,800 rpm.
2. Lacquer.

Brass doorknobs and escutcheon plates stamped from sheets which are badly die marked are given an oxidized and relieved finish as follows:

1. Cut down with Tripoli on a closely stitched buff at 8,500 fpm.
2. Pumice and water on Tampico wheel at 4,000 fpm.
3. Oxidize in liquid sulphur.
4. Relieve with buffing composition on an 8-in. loose buff at 1,800 rpm.
5. Clean, dry, and lacquer.

A brushed or satin finish is obtained by substituting operations 2, 3, and 4 with one using a greaseless composition on a cloth wheel, which is followed by lacquer without cleaning. With smooth stampings, operation 1 also may be omitted in the process.

Zinc base die castings for electric clock cases are finished to a satin chromium plate as follows:

1. Die seams polished out on a 120-grain setup wheel.
2. Grease with 180-grain setup wheel.
3. Cut-down buff using Tripoli.
4. Tampico wheel with pumice and water.
5. Nickel flash.
6. Fifteen-minute chromium plate.
7. Tampico wheel with pumice and water.
8. Wash and dry.

The **0.30 carbon steel forging** for orthopedic stirrups is finished as follows. If the surface of the forging is smooth and the flashes well removed, the operations can be as outlined below. If the flashes are prominent, it may be desirable to grind them off, using a solid abrasive wheel on a two-wheel grinder, and next smooth the forging, using an 80-grain abrasive set up on a canvas sewed wheel.

1. Dry-fine, using a 150-grain aluminum oxide abrasive glued to the face of a built-up canvas disk wheel spirally sewed, operating at 7,000 sfpm.

2. Grease-finish, using a built-up canvas wheel set up with aluminum oxide abrasive of 220 grit and grease at 6,500 fpm.

3. Cut-down buff, using a spirally sewed cotton buff wheel at 8,500 fpm and 240 emery cake. Hold the work with fairly good pressure against the wheel

until the desired luster is obtained. Apply frequently only a little of the emery cake.

4. Color-buff, using on a once-sewed cotton buff a green chromic oxide cake at 10,000 fpm.

If the part is to be **plated,** it is now copper flashed and buffed. The copper adheres to the steel better than nickel. It is soft and when buffed tends to flow and fill in irregularities left on the steel. When buffed, it leaves a smoother and more uniform surface with a high luster to take the nickel plate. Copper striking is not necessary in production work where conditions are carefully controlled. The nickel plate is next applied and color buffed with a lime composition on a ${}^{64}/_{68}$ loose buff. If chromium plate is required, the part is next chromium plated, which requires no final coloring unless it is burned or cloudy.

The total thickness of the three plates on automotive parts after buffing averages 0.0008 in. The chromium plate is about 0.00002 in. thick. The copper thickness is equal to or greater than the nickel. About 25 per cent of the total thickness is removed by buffing. Under well-controlled conditions nickel is frequently plated directly on steel.

MACHINES FOR GRINDING, POLISHING, BUFFING, HONING, AND LAPPING

Classification

Many machine tools have been developed for the grinding trade. They consist of many sizes and special types, each designed to handle a particular class of work to the best advantage.

Grinding machines are designated by the purpose of the operation, the type of grinding operation, the shape of the surface produced, the name of the part ground, or features of construction as outlined in Table 4 and described separately below.

Rough-Grinding Machines

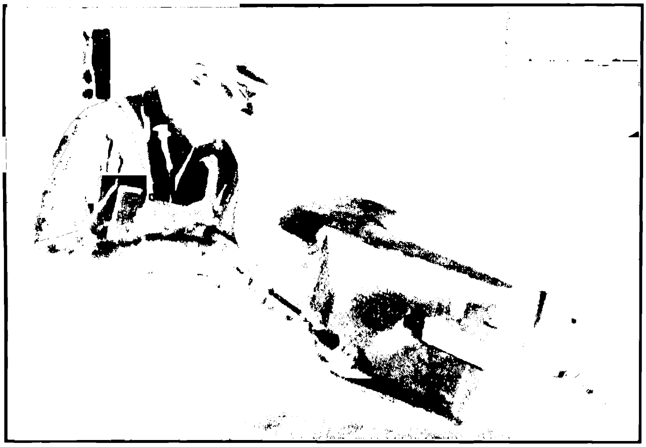
In rough grinding, the work is usually held in the hand and pressed against the abrasive wheel or the wheel may be moved by hand against the work.

A swing-frame snagging machine is used for cleaning or smoothing large castings. The machine is supported by a crane and moved about by the operator over the work. The motor at the rear end drives the wheel by two V belts, and the operator can swivel the wheel 90 deg each side of the vertical. To clean large steel castings a swing-frame grinder would use an aluminum oxide, resinoid-bonded wheel 24Q4T–H at a surface speed of 9,500 fpm or a vitrified 24-P wheel at the normal speed of 6,500 fpm.

A portable grinder, direct motor driven for cleaning castings, welded work, and other rough grinding, polishing, or buffing jobs, is shown in Fig. 10. Grinding, polishing, buffing, or wire-brush cleaning wheels

TABLE 4. CLASSIFICATION OF GRINDING OPERATIONS AND MACHINES

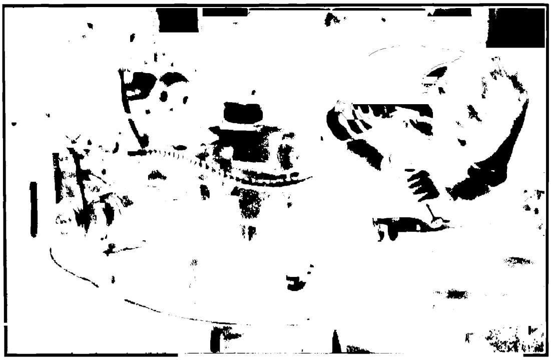
Purpose	Type of Grinding Operation	Type of Machine
Rough removal of stock	(*a*) Snagging (*b*) Offhand grinding	1. Swinging frame grinder 2. Portable grinder 3. Flexible-shaft grinder 4. Two-wheel grinder 5. Disk grinder
Cutting off or parting	(*c*) Cutting off with circular abrasive wheel	6. Cutting off (see *Sawing*)
Surface finishing	(*d*) Polishing and buffing	7. Band polisher 8. Two-wheel combination grinder 9. Two-wheel polishing machine 10. Two-wheel buffing machine 11. Semiautomatic polishing and buffing machines
Precision grinding (accurate generation and sizing of surfaces)	(*e*) Cylindrical: straight, tapered, or formed	12. Tool-post grinder 13. Cylindrical grinder 14. Crankshaft grinder 15. Centerless grinder
	(*f*) Internal: straight, tapered, or formed	16. Internal grinder
	(*g*) Surface: plane or molded	17. Surface grinders (*a*) Reciprocating table with horizontal or vertical wheel spindle (*b*) Rotary table with horizontal or vertical wheel spindle
	(*h*) Miscellaneous curved surfaces	18. Machines for grinding gear or worm teeth, ball-bearing balls, cams, and threads
Production of keen cutting edges	(*i*) Sharpening cutting tools	19. Machines for grinding single-point cutting tools, drills, milling cutters, reamers, taps, dies, knives
Very accurate finishing and sizing	(*j*) Honing	20. Cylinder honing machines
	(*k*) Lapping	21. Lapping machines
Reduction of material to desired particle size or form	(*l*) Grinding pulpwood for paper	22. Pulpwood grinder



Courtesy Norton Co.

Fig. 10. A Buckeye Portable Tool Company "Hercules" No. 364-4 General-Purpose Pneumatic Portable Grinder, Buffer, and Wire-Brush Cleaning Tool.

This tool is equipped with a Norton Co. conical wheel of 24 grain, N grade, vitrified bond for cleaning the fillets and surfaces of castings in a foundry. A portable pneumatic face grinder is shown on the bench to the right.



Courtesy R. G. Haskins Co.

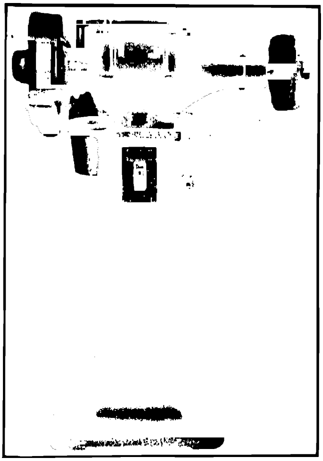
Fig. 11. Finish Grinding a Drop-Forging Die with the Type HS-4 Flexible Shaft Grinder with Pedestal Mounting.

The ¼-hp motor drives the countershaft at 1,800, 2,800, or 4,300 rpm or by transposing the pulleys at 3,100, 4,800, or 7,500 rpm. The flexible shaft is 5/16 in. diam. and 5 ft long. The 7,500-rpm speed is recommended when all small-diameter grinding tools are used, and the 3,100-rpm speed for drilling and burring operations.

are used interchangeably. Machines of this type are operated pneumatically or by self-contained electric motors.

Flexible shaft machines, Fig. 11, are made in numerous types and sizes. These machines may be used for offhand grinding as illustrated, for polishing and buffing, or, when provided with small metal tools, may be used for drilling, burring, etc. When provided with abrasive pencils or mounted points, the machine may be used for grinding small fillets, die sinking, or sharpening small tools. With a right-angle drive attachment, face grinding or polishing and wire scrubbing may be done. The chuck is sometimes rigidly fixed in the tool post of a lathe and then fed by power for drilling or grinding.

A motor-driven **two-wheel grinder** is shown in Fig. V-27. The head may be mounted on a bench or floor-type pedestal. Both wheels are well guarded and provided with a work support. Machines of this type are made in a variety of sizes from ¼ hp with 6-in.-diam. wheels to 15-hp motor with 30-in. wheels for general rough grinding on one end, and a fine grain wheel on the other end for finish grinding. The two-wheel grinder is often built with similar wheels or as a **combination grinder** with a straight wheel for miscellaneous work on one end and a cup wheel for tool grinding on the other. The cup wheel should be provided with a drum-type guard adjustable for wheel-face wear, and a special adjustable tool rest with a graduated scale. The straight grinding wheel should be equipped with a universal adjustable guard, work support, exhaust port, and hinged and flanged inclosing cover, for roughing or general-purpose grinding. The machine may be provided with a straight grinding wheel on one end and a polishing and buffing spindle on the other end, Fig. 12. Machines of this type also are made with a straight grinding wheel on one end and a disk wheel on the other.



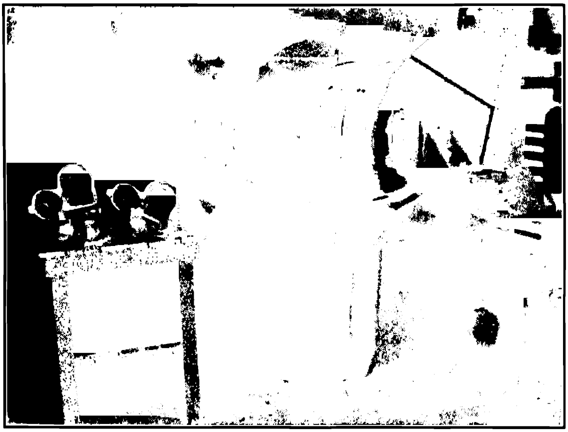
Courtesy Van Dorn-Black and Decker Co.

FIG. 12. A Combination Grinding and Buffing Machine with a 1-hp, 1,800-rpm Motor.

A grinding wheel is mounted on the left spindle while a loose cotton buff is on the right.

A double-disk motor-driven face grinder, Fig. 13, is used to grind flat surfaces on comparatively small parts. The tables carrying the work rock or oscillate manually or mechanically and feed the work toward the abrasive disk. With the manually oscillating table, one operator is required for each wheel. In the mechanical type the operator loads and unloads each fixture while that in the other is being ground.

Formerly the grinding member consisted of a coated cloth disk glued to the face of the steel wheel; then a solid abrasive wheel about $\frac{1}{4}$ in. thick with a cloth back was used. Modern practice is to use rubber-bonded wheels mechanically attached to steel driving disks. Grinders of this type are made also of the double-spindle opposed-disk type as shown in Fig. 38, in which the work may be faced on both sides or ends accurately and rapidly.



Courtesy Gardner Machine Co.

FIG. 13. The Gardner No. $7\frac{1}{2}$ Two-Wheel Horizontal-Spindle Disk Grinder.

Cast-iron gear cases are being rough faced on the rear wheel and the covers on the front wheel. About $\frac{1}{16}$ in. of stock is removed over an area of approximately 20 sq in., and a production of 100 pieces per hr is obtained.

Most of the modern grinding machines of the two-wheel type are motor driven. However, a belt drive from a countershaft or motor overhead is sometimes used on machines arranged in groups, Fig. 19. In the motor-driven types, the motor may be mounted directly on the spindle or located in the base or on the back of the machine and belted to the spindle, or drive the spindle through speed change gears.

Disk grinders also are made with the disk mounted face up on a vertical spindle. The work is moved over the wheel face by hand or by power.

POLISHING AND BUFFING MACHINES FOR SURFACE FINISHING

Classification

Polishing and buffing machines are made in a number of types and sizes. The following represent those used in metal working for finishing surfaces with emphasis on finish rather than dimensional accuracy.

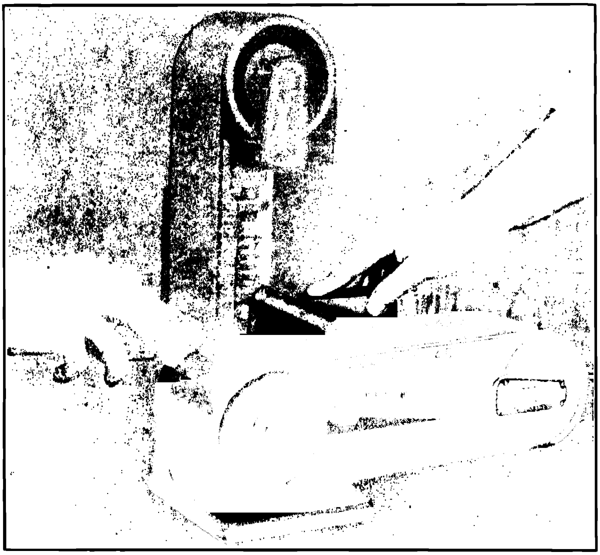
1. Band polishing machines with belt arranged vertically or horizontally.
2. Disk polishing machines with vertically or horizontally mounted abrasive disks.
3. Two-wheel combination grinding and polishing or buffing machines for miscellaneous work.
4. Two-wheel polishers or buffers, either belt or motor driven, and arranged for bench or floor mounting.
5. Semiautomatic polishing and buffing machines of the continuous-feed or indexing type.

Coated abrasive belts are often used in dry or wet polishing work. Many of these belts are narrow and flexible so they may be passed through an opening to polish interior surfaces, such as the handles of shears and surgical instruments. Others are wide and used with a rigid back as shown by the small **surface polisher** in Fig. 14. These surface polishers may be belt or direct motor driven and provided with various fixtures for specific classes of work. Bevel attachments may be arranged over the belt so that two surfaces, having a definite angular relation, may be polished on a rough part. In the small machine shown, the work is simply held by hand against the abrasive belt, while the face is being made smooth. The belt tension is regulated and maintained by the compressed coil spring. Coarse- and fine-grained belts are quickly interchangeable. Belts ¼-26 in. wide are used. Tolerances of 0.0005 in. with surface quality of 2.5 microinches, r.m.s., are possible.

Polishing is done with endless belts for running over a flexible faced wheel against which the operator forces the work, with the other end of the belt running over a pulley at the rear, above or below the working wheel — depending upon the nature of the work, as shown in Fig. 15. The belt gives several times the circumference of a set-up polishing wheel and provides a uniform, fast-cutting, cool-running abrasive that is tough enough to withstand high pressures and high polishing speeds. Belts of this type give production greater and cheaper than that obtained with set-up polishing wheels. A typical operation is the polishing down of the corner welds on 20-gage ingot iron stove ends. A backstand belt of No. 36 grit running over a

16 in. diam. by 4 in. face contact wheel operates at 7,300 fpm. This procedure is 60 per cent faster than when using a set-up polishing wheel, and a better finish is obtained.

Disk polishing machines, similar to the disk grinder, are used for surfacing small miscellaneous parts in the machine shop. Machines with multiple spindles arranged vertically over a flat-top table with wheel face down are used for polishing sheet metal and plate glass.



Courtesy Hammond Machinery Builders, Inc.

FIG. 14. Model 400 Abrasive Belt Dry Grinder for Small Work.

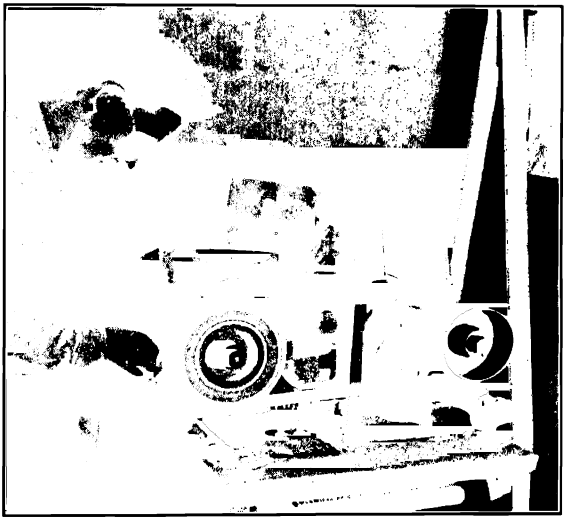
This grinder may be mounted for horizontal work, as shown, or vertically. The table is 5 in. by 10¼ in., and the endless abrasive belt is 4 in. wide and 36¼ in. long.

As the wheels rotate, the table is moved continuously, transversely, and longitudinally underneath.

Metallographic polishing machines usually consist of a disk mounted on the upper end of a vertical driving shaft. Disks of broadcloth or felt are attached by a compression ring to the disk. Each disk is impregnated with an abrasive for each of the several operations required. Surface quality of 1–4 microinches, r.m.s., is obtained.

A heavy-duty, two-wheel polishing and buffing machine of the floor type, having two spindles each equipped with **air-exhaust guards,** is shown in Fig. 16. The motor, mounted back of the spindle, drives the spindle by a short belt. The motor also drives a fan which carries all dust particles from the wheels through the guards to a washer in the base of the machine where the air is cleaned. A small centrifugal pump driven from the left spindle furnishes a water spray for this purpose. A stand with a resin-bonded backstand belt is shown in Fig. 15.

Continuous-feed polishing machines are used frequently for large-quantity production. Numerous work carriages are fed past the wheels by an endless belt driven by a motor through reduction gears.



Courtesy Minnesota Mining and Mfg. Co.

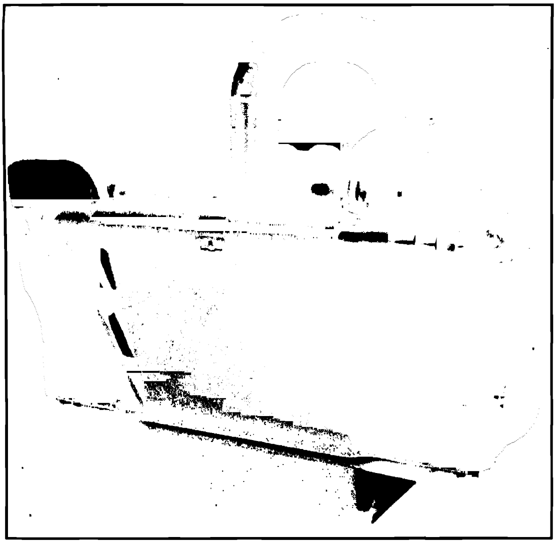
FIG. 15. A Small Belt-Type Polishing Machine in Which the Belts Running over the Forward Flexible Wheel Carry the Abrasive.

The backstand is belt-driven from the motor underneath. An induced draft of air carries away the dust particles, and the operator's eyes are protected by goggles.

Fixtures of any type may be attached to the belt. They are loaded as they pass under the wheels and are returned empty on the underside to the loading position. Each motor-driven polishing head is mounted on the end of a counterbalanced arm to permit vertical adjustment as the work passes below the wheel.

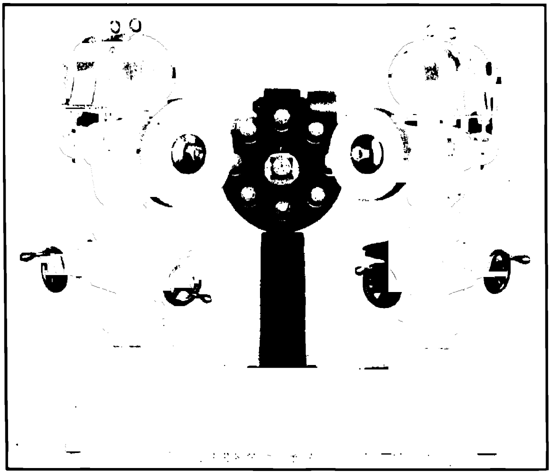
The number of fixtures or carriages and polishing units is dependent on the nature of each particular job. Items such as bumpers, wrenches, planes, skates, and flatirons may be polished and buffed on machines of this type.

An automatic polishing and buffing machine consists of a multiple-



Courtesy United States Electrical Tool Co.

FIG. 16. The Model 120 Polisher and Buffer with a Self-Contained Exhaust System and Air Cleaner.



Courtesy Acme Manufacturing Co.

FIG. 17. Type L-8 Two-Wheel Unit, Semiautomatic Polishing and Buffing Machine with 8-Spindle Indexing Fixture.

spindle fixture to hold and slowly rotate the work while the spindles are indexed from the nonrotating loading position at the bottom to a rotating contact with the buffing wheel. One or more wheels may be used and the work indexed from one to the other for cutting down and coloring, to give two operations at one chucking, Fig. 17.

The cutting-down buff on the left consists of four 20-ply cotton sections sewed radially and operates at 2,400 rpm. The coloring buff consists of four 20-ply cotton sections sewed once around the hole and operates at 2,400 rpm. Tripoli composition is used for cutting down, and a soft silica compound for coloring. Small brass stampings are finished at the rate of 100 pieces per hr. Simple cylindrical and cupped work, when made in quantities, is suited to machines of this type.

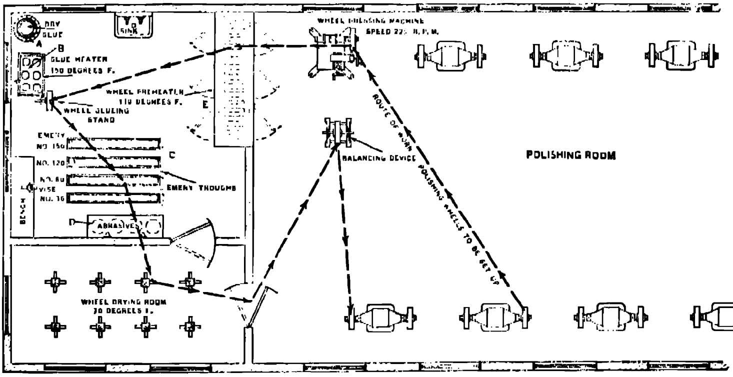


FIG. 18. A Layout of a Polishing Department with Facilities for Treating the Used Polishing Wheels.

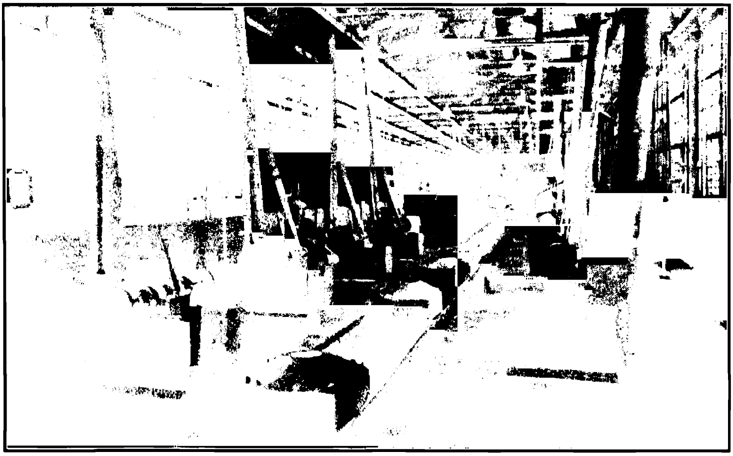
The arrows indicate the path of the worn wheel until it is ready for use again.

Polishing-Room Layout

A plan of a polishing and buffing room for small parts is shown in Fig. 18. Facilities for taking care of wheels are shown at the left end. Such a layout depends on the quantity and size of the work and the type of machines used. Figure 9 shows the arrangement of a small self-contained polishing and buffing room for small work. Figure 19 shows a polishing and buffing department, arranged with a conveyor, for larger parts in considerable quantities.

Dust Removal and Safety

Polishing and buffing departments should be equipped with dust-collecting systems so that the abrasive and metal dust will be carried away and the danger of flying particles reduced. In dry grinding and polishing, goggles should be used to protect the eyes, unless adequate guards are provided. The Kirk and Blum Manufacturing Co. installed an exhaust system in the grinding and polishing room of the Maytag Co., Fig. 19, which had an average suction of 4½ in. static pressure maintained by three 90-in.-diam. fans on the roof. For a production of 1,000–1,400 washing machines per day, twenty-two grinding and polishing operations are required on each aluminum tub and nineteen operations on each crown, in addition to other miscellaneous parts routed through the polishing room. This work involves 120-grit size polishing lathes and 40 belt grinders. A carload of aluminum and abrasive dust is collected about every 25 days, or about 2 tons every 9 hr.



Courtesy Kirk and Blum Manufacturing Co.

FIG. 19. One of the Polishing Departments of the Maytag Company.

The aluminum tub has various polishing and buffing operations performed as it is moved along the central conveyor. Two-wheel polishing stands are belt-driven at 2.700 rpm by overhead 7½-hp motors. The inside of the tub is roughed out with No. 36 grain abrasive set up on muslin wheels. A No. 60 grain abrasive setup wheel is next used, and then followed by wire brushing. The outside of the tub is roughed with a No. 36 grain abrasive set up on an endless belt, and is followed by a No. 80 grain on a belt for finishing.

Such a system makes far better working conditions, reduces labor turnover, effects a saving in cleaning-up labor, adds to safety, and increases production by approximately 20 per cent. It also protects other machinery in the room from the fine dust and particles of abrasive.

PRECISION GRINDING

In precision grinding, the work and grinding wheel are mounted rigidly but adjustably with respect to one another as required in the various methods of grinding, so that parts may be ground to shape and size quickly and accurately. The various types of precision grinding machines are listed in Table 4 and described separately below.

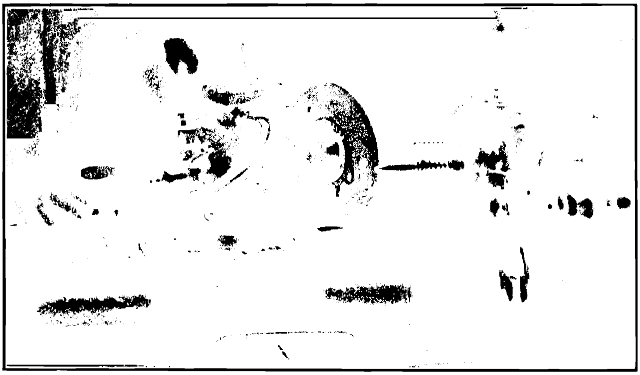
CYLINDRICAL GRINDING MACHINES

In cylindrical grinding internal or external surfaces, the work is held rigidly on centers or in some form of chuck or holding fixture and is rotated slowly. The rapidly rotating wheel is fed against the work. When the work surface to be ground is longer than the face of the wheel, the work is slowly traversed hydraulically, mechanically, or manually past the wheel mounted on a cross slide. In some cylindrical grinders the work traverses past the wheel, and in others the wheel traverses past the work. At either or each end of the table traverse, the wheel slide is fed toward the work, or the worktable, mounted on a saddle, is fed toward the wheel until the desired work size is reached. When the wheel face is as wide as the length of the surface being ground or when it is impracticable to **traverse-grind** the work, the wheel may be fed in with no traverse of the wheel or work. This is called **plunge grinding.** Wheel speed, wheel feed, work speed, table speed, and length of traverse are independently adjustable to suit the type of machine and conditions outlined above in connection with *Proper Conditions for Grinding.*

A **tool-post grinder** is a portable machine which may be clamped in the tool post of a lathe, miller, or planer for various grinding operations. The wheel may be mounted on the motor spindle when large-diameter wheels are used, Fig. 20, or on an auxiliary high-speed spindle when small-diameter wheels are used, Fig. 22.

Cylindrical grinding machines may be **plain or universal.** In both types the table may be swiveled in a horizontal plane about its center for grinding tapers. In the universal machine the headstock may be swiveled on its graduated base as required for grinding tapered holes in work held in a chuck on the headstock spindle, the wheel head may be swiveled in a horizontal plane on a graduated base for wheel position, and the whole wheel slide swiveled on a secondary base for angular in-feed. Universal machines are equipped with a wide variety of accessories, such as internal grinding equipment, Fig. 22, to do almost any type of grinding operation. The spindle of machines of this type is of heat-treated high-carbon or alloy steel carefully finished and run in adjustable bronze bushings, force lubricated with filtered oil.

A **plain cylindrical grinder** set up for traverse grinding is shown in Fig. 21. This is a self-contained motor-driven machine. It is made with a 14- and 16-in. swing, each in eight sizes to take from 18 in. to 168 in. between centers. A 30-in.-diam. wheel driven by a 20–40-hp motor is used, depending upon the width of the wheel face, the size of the machine, and the service required. The table ways of this grinder have a continuous-pressure feed lubrication with filtered oil. The table may be swiveled in the horizontal plane to grind slight tapers. A variable-speed motor, having a three to one speed range to give any of twenty-four work speeds, drives the headstock faceplate through a silent chain to a steel worm and bronze worm wheel. A direct-current generator to drive the headstock motor is included in the regular machine equipment. The rheostat for controlling the work speeds is shown at *A*. Any of twelve table traverse speeds is obtained by adjusting the lever *G*. A third small motor drives the coolant pump. The tailstock center may be withdrawn to remove the work by a single screw handwheel or by a combination screw and spring lever. The truing diamond bar and holding bracket are shown mounted on the forward end of the tailstock, and a single back rest supports the work between centers.



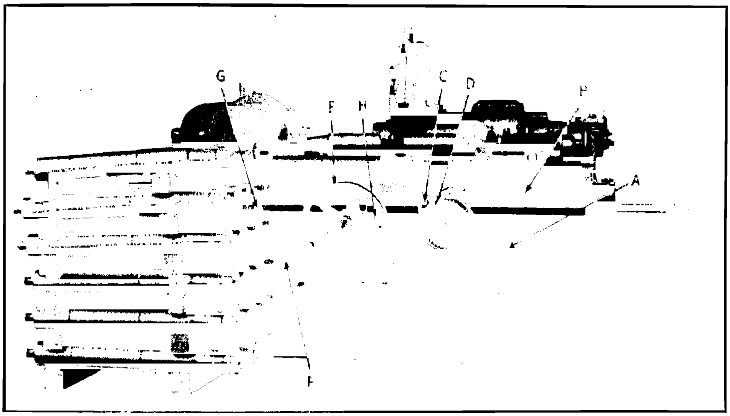
Courtesy United States Electrical Tool Co.

FIG. 20. A Tool-Post Grinder Clamped in the Tool Post of a Lathe Is Set Up for Grinding Lathe Centers with a Straight Wheel.

The compound rest slide is swiveled to an angle 30 deg from the axis of the spindle. The grinder axis is parallel to the compound rest feed screw. The wheel is reciprocated along the conical point of the center by the compound rest screw and is fed to depth by the cross-feed screw.

Plain grinding machines of rigid construction are sometimes used for

plunge grinding. A single wheel may be fed into the work radially, a small amount of each revolution of the work, or two or more wheels of equal or different diameters may be used to grind different surfaces on the same part concentrically within very close limits in one operation. Surfaces close to or between shoulders may be ground in this way. It is desirable if possible to give the wheel or work a short-stroke reciprocation.



Courtesy Cincinnati Milling Machine and Cincinnati Grinders, Inc

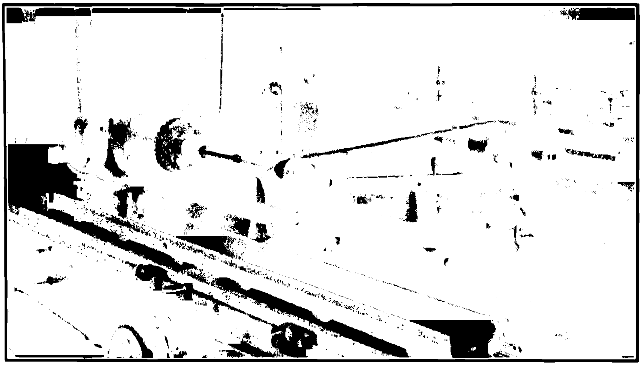
A, work-speed rheostat; *B*, swivel table adjustment; *C*, positive stop to cross feed; *D*, handwheel for cross feed; *E*, handwheel for table travel; *F*, wheel truing speed; *G*, work- and table-control lever; *H*, table-reversing lever.

FIG. 21. The Cincinnati Self-Contained Plain Grinder, 14-in. Swing by 48 in. between Centers, Set Up for Grinding Spindles.

Heat-treated chromium-nickel steel spindle forgings, carried on dead centers and driven by a dog on the small end, are being rough and semifinish ground at the rate of one spindle every 35 min. Three diameters are ground to a tolerance of plus 0.0000 in. and minus 0.0002 in. with a surface finish of 20 microinches, r.m.s.

Gages are attached to cylindrical grinders to control the accuracy of the work. The gage rides on a transverse circle of the work on three points at approximately 0, 90, and 180 deg as the grinding wheel feeds in. Two of the points at 90 deg are fixed; the third point operates the indicating mechanism whether a dial gage or electric or pneumatic device. The dial gage merely indicates the size of the work; the operator controls the machine. When the correct diameter is reached with the Norton Co. **electric gage,** an electrical contact is made which stops the wheel feed and automatically lifts the gage from the work. The wheel remains in contact with the work for a short period to spark out and then recedes rapidly to a position which facilitates rapid and safe reloading. When this device is used on semiautomatic machines, the stopping and starting of the work revolutions, the rapid travel of the wheel to the work, the feeding during the grinding, and the operation of the footstock and steady rest are all controlled automatically.

The Landis **air-sizing device** is used for external or internal cylindrical grinding operations whether the hole be straight, tapered, splined, radial, keywayed, interrupted, or blind. The limit of accuracy is



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 22. A Belt-Driven Universal Grinding Machine Set Up for Internal Grinding.

Straight or tapered bores may be ground to a high degree of accuracy. A pack-hardened, low-carbon-steel spur gear having a bore $1\frac{3}{8}$ in. in diam. by 4 in. long is having 0.007 in. of stock removed at the rate of 0.00025 in. per pass. The production time is 5 to 6 min each, while the work speed is 376 rpm and the table speed is 34 in. per min. A Bay State Abrasive Products Co. wheel of 9A-60K6-V2 is used.

claimed to be within 0.00025 in. Its operation is based on the principle that, if air is escaping from a pressure line, the pressure in this line is affected by the size and shape of the escaping outlet. In external grinding, the device bears constantly against the work on two supporting diamond points. The air outlet is between these two diamond points. As the work diameter is reduced, the gap between the work and outlet is reduced and the pressure slowly builds up in the air line. This change in pressure changes the level of the mercury in a U tube to close electrical contacts. Just before the work reaches finished size, the mercury engages the lower of two contacts extending down from the top of the tube. An electrical circuit is thus completed which energizes a solenoid. This causes the speed of the feeding-in movement to slow down while grinding continues. When the final size is reached, the mercury, having risen by then in the tube to touch the second contact extending down from the top, completes a second electrical circuit energizing a second solenoid. This causes the wheel to move rapidly away from the work. The position of the two contacts in the tube is adjustable, as is the slow in-feed movement of the wheel. Final adjustment for size is made by changing the position of the diamond points bearing against the work. When applied to internal work, the pressure in the tube is highest when grinding starts. As the work hole is enlarged, the pressure drops, engaging the electrical contacts in the lower side of the U tube, similar to that mentioned above.

Roll grinding machines are plain grinders for finishing hydraulic rams, gun tubes, turbine shafts, and rolls for printing machines and rolling mills requiring great accuracy and excellent finish. Special features are provided on the larger machines to minimize vibration and promote rigidity. The face of the roll can be crowned slightly by means of a cambering device.

Steel rolls for cold rolling steel ranging from 9 to 30 in. in diam. and 8 to 96 in. body length, hardened to give a scleroscope reading of 94–101, are generally reground with wheels as follows: Rough-grind with an A46–L5VBE wheel removing 0.0015 in. per pass, semifinish-grind with an A100–I6VBE wheel or A100–K7B wheel removing 0.0005 in. per pass, and finish-grind with a C150–L8BL wheel. An emulsion of 1 part soluble oil to 30 parts of water is used. A surface finish of 2–6 microinches, r.m.s., is obtained. For a mirror finish of 1 microinch, r.m.s., a C500–GV or a C500–H9E wheel is used.

Chilled cast iron, granite, brass, and copper rolls are rough ground with a C30–L5E wheel and finished with a C60–L5E wheel. Rubber-covered rolls or hard-rubber rolls are ground with a C30–L5 (E or B) and fine finished with a C60–K5 (E or B) wheel.

Crankshaft Grinding Machines

The line bearings of a crankshaft are ground on a plain cylindrical grinding machine especially arranged for this work. In finish grinding crankshaft main bearings by the plunge cut, 0.025 in. of steel is removed at the rate of 40 shafts per hr when a 1 to 80 emulsion is used. The wheel, 30 in. diam. and 2.188 in. wide, rotates at 750 rpm (6,500 fpm).

Crankpins often are ground on cylindrical grinders arranged with double work head so that the work is driven from both ends to eliminate torsional strains. The shafts are chucked in special fixtures so that the crankpins being ground rotate on center.

In one installation the wheels of A54 to 60, grade O or P, medium structure 6 of vitrified bond (A60P6V) are rotated at 6,500 fpm. The work rotates at 60 fpm. The new wheels are 42 in. in diam. and are worn down to 32 in., producing approximately 100,000 crankshafts.

From 0.017 to 0.025 in. of stock is removed from each bearing with an in-feed of 0.0005 ipr. The wheel is trued with a diamond after each 25 shafts, by two passes — the first removing 0.001 in. and the second 0.0005 in. on the radius. The pins and bearings are usually finished by polishing or "superfinishing" as described below, Fig. 44.

Camshaft Grinding Machines

A camshaft grinding machine has a set of master ground cams, one corresponding to each cam on the shaft to be ground, located in the work head, as shown in Fig. 23. A single roller rides on one master cam while the corresponding cam on the shaft is being ground.

With the throw of the main control lever, the hydraulically controlled work carriage brings the first cam into grinding position. The wheel feeds in rapidly and the work cradle swings back, bringing the first master cam in contact with the roller. The grinding in-feed is now engaged and the wheel is fed forward until it comes against the positive sizing stop. The work rotates at approximately 80 rpm for about 9½ rev of the work for the rough grinding, after which the in-feed is reduced for the finish grinding and the work speed reduced to 40 rpm for about 2½ rev. After finishing the first cam in this manner, the work cradle is swung forward and the wheel moved backward while the second cam on the shaft is brought into grinding position and the master cam roller engages the second master cam. This operation is repeated until all cams are finished. Figure 24 shows a close-up of an automobile camshaft in its grinding position. A hardened pin engages slots in the carefully finished blade attached to the front of the carriage to locate the several cams of the shaft in grinding position.

FIG. 23. A View of the Work Head of the Landis Camshaft Grinder with the Cover Removed to Show the Master Cams and Roller.

A typical light 8-cylinder camshaft is ground in three operations on a battery of Landis grinders as follows:

In rough grinding 0.020–0.030 in. of stock is removed and 16 shafts, equivalent to 256 cams, are ground per hr to a tolerance of 0.003 in. One man is able to operate four machines.

In semifinishing, 0.012–0.015 in. of stock is removed, and 11 shafts are finished per hr. One man operates three machines. This semifinishing operation is used only in very large production.

In finishing, 0.005–0.007 in. of stock is removed, and 12 shafts are finished per hr. Tolerances of 0.0015 in. on the diam. and 0.002 in. for timing are maintained.

The Norton Co. **automatic camshaft grinding machine,** after being loaded and started, rough-grinds each successive cam on the shaft. The wheel is then trued and the work speed reduced while each cam in turn is finished to size. All these operations are included in the automatic cycle.

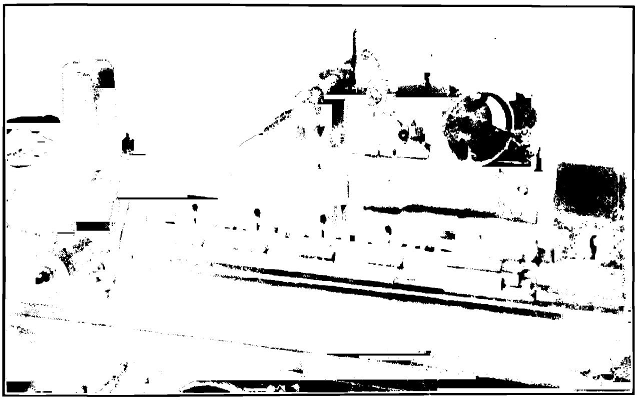


FIG. 24. A Close-Up View of the Landis Camshaft Grinder.

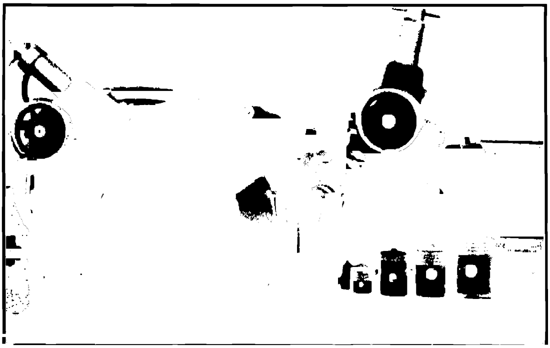
The camshaft is supported on centers and by four intermediate work rests.

Thread-Grinding Machines

The production of screw threads for lead screws and other work requiring extreme accuracy as to pitch diameter and lead has led to the development of special machines for this purpose. The Ex-Cell-O Corp., for example, has a complete line of precision thread grinders designed to cover the bulk of industry's thread-grinding needs. Work up to 90 in. between centers and 12 in. in diam. can have threads ground on its external surface by the largest of these machines. Continuous and multiple, internal and external, right and left end, straight, tapered, and relieved threads can be ground at any pitch from 1 to 80 per in. of any thread form. Tolerances on the pitch diameter of ±0.0002 in. can be held, lead can be held to ±0.0002 in. in any in. or ±0.0005 in. in any 12 in. These machines are hydraulically operated and electrically controlled by levers and switches located on the front of the machine. A master lead screw with hardened and precision-ground threads closely fitted to a bronze nut drives the worktable in both directions. This lead screw is driven through gears from the work spindle, which in turn is driven by a hydraulic motor with variable speed. This provides an infinitely variable work spindle speed range. Adjustable dogs are arranged at the front of the machine to actuate plungers in the hydraulic control panel to stop and reverse the table travel automatically, and also change work spindle speeds at either or both ends of the stroke. Taper threads may be ground, and the machine is provided with an automatic backlash compensator and back-off attachment for grinding relieved threads on taps, hobs, etc. The machine is equipped with a pantograph type of wheel dresser to control the motion of three diamonds which dress both sides and the periphery of the wheel.

CENTERLESS GRINDING MACHINES

The centerless grinding machine for external cylindrical or formed work consists of two abrasive wheels each mounted on a horizontal axis, with the wheel surfaces opposed to each other. An adjustable work-supporting blade is mounted between the two wheels.



Courtesy Cincinnati Milling Machine and Cincinnati Grinders, Inc.

FIG. 25. Centerless Grinding Cylindrical Work by the Through-Feed Method.

Automobile pistons of cast iron $4\frac{15}{32}$ in. long and 3.1815 in. in diam. are being ground to within plus or minus 0.0002 for roundness, straightness, and size when removing 0.005 in. of stock in three cuts in the No. 2 centerless grinder at the rate of 175 finished pistons per hr. Surface finish is 4–12 microinches, r.m.s.

The larger wheel, Fig. 25, known as the grinding wheel, is 20 in. diam. and driven at a speed of 6,000 sfpm by a 15- or 20-hp motor. The smaller wheel, known as the **regulating wheel,** rotates slowly and acts as a brake to prevent the work from spinning as it is held against the grinding wheel. This determines the rotating speed of the work. The regulating wheel acts as a work support and, when tilted, feeds it transversely. It is 12 in. in diam. and 4 or more in. wide and is driven, through change gears located on the right end of the machine, at any of twelve speeds from 12 to 330 rpm. The highest speed is used when truing. The widths of the grinding and regulating wheels are selected to suit the work. Both wheels rotate clockwise. The regulating wheel is mounted on a double slide to permit adjustment of wheel and work rest for size variation in the work being ground, and to move this wheel to and from the grinding wheel. The axis of the regulating wheel can be tilted from the horizontal to suit any grinding condition to feed the work continuously across the face of the grinding wheel, in at the front side and out at the rear.

The cylindrical bars, extending radially upward from each wheel, carry diamonds or wheel truers on their lower ends. The truer for the regulating wheel, after being adjusted for depth, is fed on a dovetail slide across the wheel face by the handwheel screw, while that for the grinding wheel is usually fed hydraulically. Because of the versatility of the centerless grinder, the wheel faces must be trued to a great variety of different forms. A cam of any desired contour may be inserted as the upper gib of the cross slide to give this form.

Centerless grinding may be divided into **two general methods**: through-feed and in-feed. Modifications of these two methods make it possible to adapt the process to a large variety of work ground in small or large lots.

Through-Feed Centerless Grinding

When grinding cylindrical work of short length, as illustrated in Fig. 25, both the grinding and regulating wheels usually are 6 in. or more in width. Two of the four standard work guides are shown to guide the work into and away from the grinding cut. The two regulating-wheel guides, one on the entering and the other on the exit side, must line up exactly with the face of the regulating wheel so that the work does not deviate from a straight line in its passage through the machine. The axis of the regulating wheel is inclined from 2 to 7 deg from the horizontal, and this inclination, together with its proper rotation, feeds the rotating work across the face of the grinding wheel. The two work guides on the grinding-wheel side are not lined up exactly with the grinding-wheel face. They prevent the work from accidentally leaving its path of travel. In grinding cast-iron or aluminum pistons, as illustrated, the face of the grinding wheel is slightly crowned to open the wheel on the entering side so that the piston starts to grind easily, and the stock is gradually removed. The piston revolves before entering and after leaving the cut.

It is often necessary to pass work between the wheels more than once. The number of passes is determined by the amount of stock to be removed, the condition of the work as to roundness and straightness in the rough, the nature of the work, the tolerances allowed, and the finish required.

In grinding hardened-steel piston pins, 0.012–0.015 in. is removed in about six passes with a through-feed of about 7 fpm, giving a net production of 250–300 pins per hr. About 0.004 in. is removed at the first pass. In finish grinding the pins, 0.001 in. is removed at the rate of 28 pieces per min. An A60–J5 wheel is used with a coolant of 1 part of soluble oil to 40 parts of water The work is held round and straight within 0.00005 in. and to size within 0.0001 in. The surface finish is about 1–6 microinches, r.m.s. Small cylindrical work like piston pins ground in large quantities is sometimes fed to the wheels from an inclined chute which feeds the work continuously to the wheels by gravity.

In-Feed Centerless Grinding

The in-feed method is usually applied to headed work, such as bolts, where the cylindrical body only is ground. Both grinding and regulating wheels are of a width that more than covers the length of the body to be ground. An adjustable end-stop is provided at the rear of the machine to prevent the work from entering between the wheels too far. This end-stop also ejects the work at the finish of the cut. The axis of the regulating wheel is inclined ¼–½ deg from the horizontal. This feeds the work against the end-stop and holds it there during the grinding cut.

When loading or removing the work, the regulating wheel is moved on its slide away from the face of the grinding wheel so that enough clearance is obtained to avoid contact of the work with the grinding-wheel face. It is fed forward against a positive stop.

Formed parts also may be ground between the two wheels by the in-feed method. A tapered lathe center is dropped between the two wheels onto the work rest, and the regulating wheel is fed forward against the positive stop which determines the size of the part, after which it is ejected. Other formed sections which cannot be ejected in this manner are dropped down between the two wheels when size is reached.

When concentricity of the outer and inner surfaces of the work is desired, special fixtures may be employed, as shown in Fig. 26. The in-feed method is used in which the operator loads the parts on a mandrel and drops them between the two wheels, after which they are ground and unloaded at the rate of 700 pieces per hr.

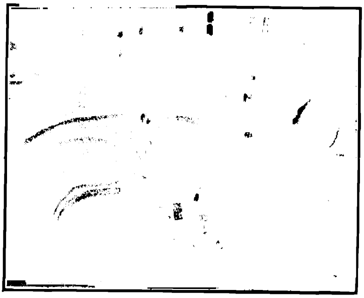
Advantages of the centerless method of grinding are as follows:

1. As applied to short or long cylindrical work, the process is continuous with the through-feed method. The in-feed method requires no chucking of the work, and thus idle machine time is reduced to a minimum.

2. During the grinding cut, the work is supported rigidly, eliminating deflection of the work. As a result, comparatively heavy cuts can be taken, and long, brittle pieces and easily distorted parts can be ground rapidly and accurately.

3. Less stock for removal is required, as in centerless grinding the largest possible circle is generated.

4. Sizing is more accurate, as feeding the regulating wheel in 0.001 in., for example, reduces the work 0.001 in. in diam. In a center-type grinder, 0.002 in. would be removed.



Courtesy Cincinnati Milling Machine and Cincinnati Grinders, Inc.

FIG. 26. Finish Concentric Grinding Pyroxylin Caps (and Barrels) for Fountain Pens on a No. 2 Centerless Grinder in One In-Feed Cut, Removing 0.010 to 0.020 in. of Stock to an Accuracy of 0.002 in.

Surface finish is 2–4 microinches, r.m.s.

When grinding the average rigid work by the centerless method, the stock removal to be considered should be at the rate of 1–1½ cu in. per min per 15 hp applied to the machine.

The Heald Machine Co. manufactures an **internal or external centerless grinder.** The reciprocation and cross-feed of the wheel are hydraulically controlled. The work is held by three rolls, one large regulating roll, a small supporting roll, and a small pressure roll. It rotates on its own surface previously finished. When the bore is ground to size, the loading arm swings up, ejecting the finished piece, automatically bringing a new part into grinding position. By means of a magazine or hopper, a completely automatic loading cycle is provided which, with the automatic grinding cycle, produces a full automatic internal grinder operating continuously as long as there is work in the loading magazine.

INTERNAL GRINDING MACHINES

Various types and sizes of machines for grinding straight, tapered, or formed internal surfaces are in use. Most of these machines operate on the principle of slowly **rotating the work** while the rapidly rotating abrasive wheel is reciprocated in light contact along one side of the bore. The work may reciprocate but not revolve, while the wheel rotates rapidly on its axis and rotates slowly eccentrically about its axis to generate the cylindrical surface of the bore.

There is a wide variety of portable and tool-post grinders, Fig. 27, used for precision grinding cylinders. High spindle speeds are available to permit the use of very small abrasive wheels under which conditions the wheels stand up well and give excellent results. Internal grinding attachments of this type also are standard equipment on universal cylindrical grinders, Fig. 22.

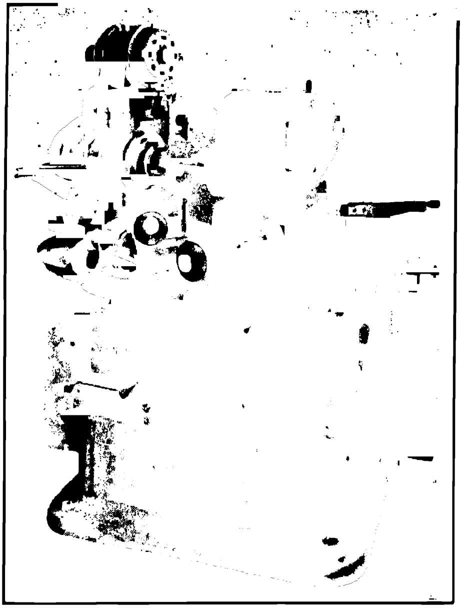
A type of **internal grinding machine** for toolroom or production work on small parts is shown in Fig. 28. The wheel rotates on the forward end of the spindle which, with the driving motor, is mounted on a cross slide which may be fed transversely by hand or power feed. In grinding tapered or cylindrical work, the carriage is reciprocated automatically. The headstock may be swiveled to any fixed position when tapered holes are ground, or oscillated for grinding spherical surfaces. The work is held in the chuck mounted on the headstock spindle and rotates to give the proper surface speed. The disk wheel, located in front of the wheel spindle carriage, operates the automatic feed device. It rough-feeds the wheel transversely to within 0.001 in. of size, as indicated by the electric gage shown above the work; then a cam action engages a fine-finishing feed which continues until the part is ground to size, when the power feed is disengaged.

Courtesy Dumore Grinder Co.

FIG. 27. A Tool-Post Grinder Set Up on an Engine Lathe.

Grinding a $5/32$-in.-diam. hole in a blanking die of tool steel.

A close-up view of wheel, chuck, work, and dial indicator sizing gage of the Heald **internal grinding machine** is shown in Fig. 29. This machine is made as the plain internal grinding machine — the Size-Matic as illustrated, or Gage-Matic. Both types are production



Courtesy Van Norman Machine Tool Co.

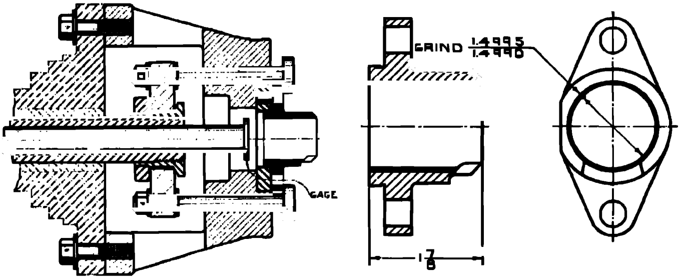
FIG. 28. The Van Norman No. 42 Oscillating Grinder Arranged to Grind the Internal Spherical Surface of the Ford Universal Joint.

FIG. 29. A Close-Up View of the Heald No. 72A Plain Internal Grinding Machine Arranged with a Dial Indicator for Sizing (Size-Matic).

The chuck- and wheel-guards are raised. The diamond truing device is shown just back of the wheel.

machines. The Size-Matic is more universal and is used in production work where the Gage-Matic cannot be used, as on tapered or blind holes. A hydraulic drive is provided for the table which gives great flexibility of reciprocating speed. An automatic grinding cycle on the Gage-Matic machine, Fig. 30, is arranged as follows:

1. Operator chucks work and throws over the starting lever.
2. The wheel advances to the work at rapid traverse, changing to roughing speed as it reaches the work. The guard is raised, and the work head and cutting-fluid pump start.



Courtesy Heald Machine Co.

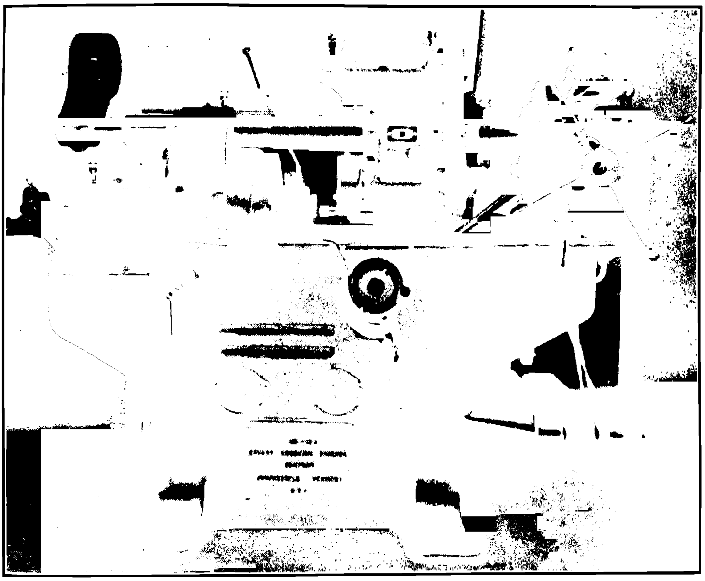
FIG. 30. A Sectional View of the Chuck and Work in a No. 72A-3 Gage-Matic Internal Grinding Machine.

Cast-iron valve-guide bushings are being ground at the rate of 75 per hr. They are centralized in the backing plate by its projecting hub and one dowel pin, and clamped by two round-head bolts operated hydraulically. The bore had been reamed previously, leaving about 0.006 in. of stock. The tolerances are 0.0005 in. on the diam. and 0.0002 in. out of round and taper. A coolant of 1 part soluble oil and 50 parts water is used.

3. Fast rough grinding with roughing feed continues until the roughing plug gage enters the work at the rear to indicate that the work is within 0.002–0.003 in. of finished size.
4. The wheel is withdrawn from the hole, and the diamond drops into position for truing the wheel.
5. The table speed changes to slow truing speed while the wheel is trued.
6. The wheel returns to the hole, the diamond swings back to its resting position, the table speed changes to that required for finishing, and the wheel feed is reduced for finishing.
7. Finish grinding progresses with slow finishing speed and finishing feed.
8. When the finish size is reached, the finish plug gage in the spindle back of the work enters the work at the rear, the wheel withdraws at rapid traverse, is guarded, and all units come to resting position.

The Heald **duplex internal grinder** grinds aligned holes in the opposite ends of work, such as wrist-pin holes in pistons and holes in cluster gears. The work is held in a central fixture and each spindle operates independently.

The Bryant **semiautomatic internal grinder,** Fig. 31, has a wheel slide supported on the overhead cylindrical bar to permit cross-feed and longitudinal traverse. Both wheel spindles are driven by the one motor through the endless belt. The small straight wheel is for internal grinding, and the large cup wheel is for facing. The grinding of straight, tapered, and irregularly formed holes is made possible by changing the position of the control bar, which bears against the rear end of the cross-feed screw, or by the substitution of a formed plate. When the control bar is parallel to the wheel spindle, straight cylindrical holes are ground. It is swiveled to an angular position for grinding tapers, and is replaced by a templet to grind holes of any irregular longitudinal contour.



Courtesy Bryant Chucking Grinder Co.

FIG. 31. The No. 12-A Semiautomatic Two-Spindle Hole and Face Grinder.

For hole and face grinding, Fig. 32, the wheel slide takes two successive positions, the first to present the small wheel for the internal grinding operation, and the second in which the small wheel is swung back to bring the large face-grinding wheel into its operating position.

The face and outside of the pilot of the cover for a pneumatic drill body are being ground by the face and periphery of the cup wheel at one operation in Fig. 33. A roller bears against the large master cam located back of the work faceplate. This swings the work spindle to give the required profile after the wheel has been fed forward to its proper position.

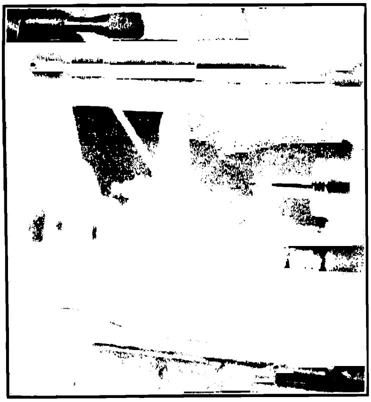


FIG. 32. Hole and Face Grinding a Refrigerator Compressor Cylinder of Cast Iron on a Bryant No. 12-A Hole and Face Grinder in One Chucking.

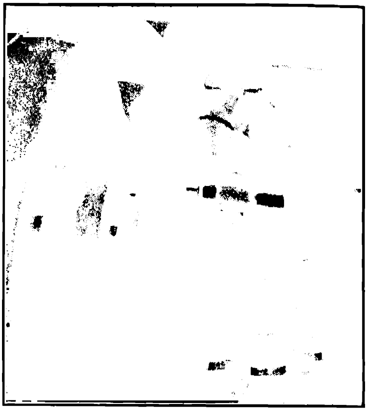


FIG. 33. A Setup on the Bryant No. 12 Internal Grinding Machine for Cam Attachment Grinding and Facing.

SURFACE GRINDING MACHINES

Classification

Surface grinding machines are designed to produce accurate and smooth surfaces on parts. Surface grinders are constructed as follows:

1. With reciprocating worktable and (*a*) straight wheel mounted on horizontal spindle, Fig. 34, (*b*) cup wheel on vertical spindle, or (*c*) cup wheel on horizontal spindle.
2. With rotary table and (*a*) straight wheel mounted on horizontal spindle, or (*b*) cup wheel on vertical spindle.
3. The single or double opposed disk.

Small **surface grinding machines** with reciprocating table and straight wheel mounted on a horizontal shaft are used for small toolroom work. The table may be fed longitudinally by hand, mechanically, or hydraulically. Reversing is accomplished by adjustable dogs on the side of the table. The table may be fed transversely by hand through a small crank wheel, or mechanically at each reversal of the longitudinal travel in either direction. A setup on a larger machine of this type is shown in Fig. 34. A flat magnetic chuck and a wet grinding attachment, consisting of table guards and tank with circulating pump, is used. The tank should be provided with baffle plates for settling the cutting fluid, and be cleaned easily. If cast iron is frequently ground, an exhaust system may be installed to draw the dust away from the work through the wheel guard.

The **vertical-spindle reciprocating-type surface grinder**, Fig. 35, employs a cup-type abrasive wheel. Automatic down-feed of the wheel spindle for each stroke of the table is provided.

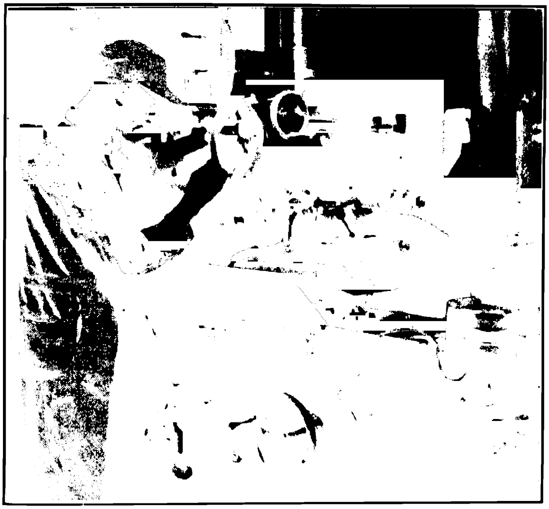


FIG. 34. Straight-Wheel Surface Grinding on a Norton Co. 6- by 10- by 36-in. Type C Surface Grinder in Which the Work Is Mounted on an O. S. Walker Co. Electric Chuck.

An A46-I18VBE wheel is used.

The Diamond **face-grinding machine** has a reciprocating table and a large segmental cup-type grinding wheel mounted to the side of the table on a horizontal spindle. Automatic feed range of 0.001–0.010 in. per traverse of the work is available for a total distance of 2⅝ in. Faceplates, special fixtures, or magnetic chucks are attached to the table to hold the work as it is passed back and forth across the face of the wheel. Machines of this type are made with wheels up to 60 in. in diam.

A **horizontal rotary surface grinder** with the table mounted on the vertical spindle and a plain wheel mounted on the horizontal spindle is shown in Fig. 36. The table may be arranged either with an 8-in. or a 12-in.-diam. magnetic chuck. If the work requires it, 3-jawed chucks or faceplates with special fixtures can be substituted. As the worktable slowly rotates, it is fed upward while the abrasive wheel is reciprocated radially over the surface of the work.

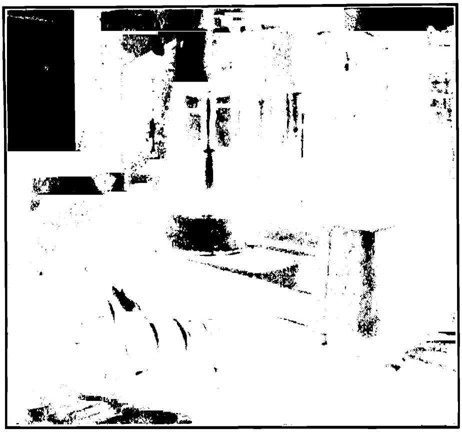


FIG. 35. High-Carbon-Steel Planer Knives Being Surface Ground on a Pratt and Whitney Reciprocating-Type Vertical-Spindle Surface Grinder Using a Segmental Wheel (32A46-G8VBE).

An O. S. Walker Co. magnetic chuck of all-steel construction is used to hold the work.

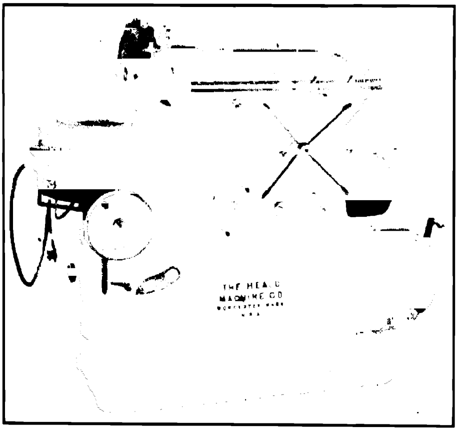
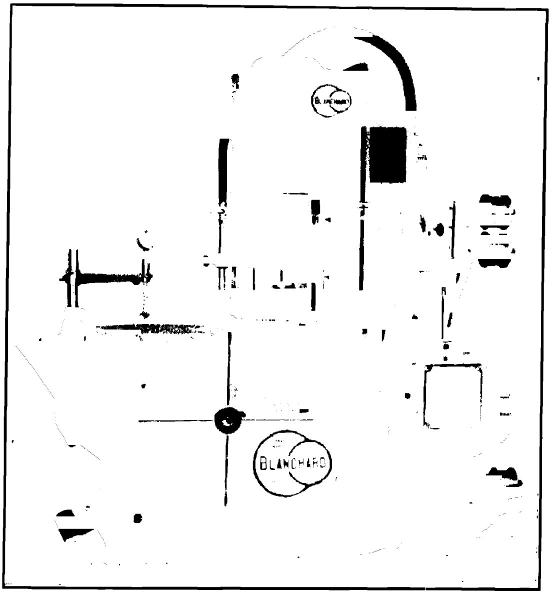


FIG. 36. The Heald Style No. 22 Rotary Surface Grinding Machine Arranged for Belt Drive to Tight and Loose Pulley.

For hardened steel, an A46-I8VBE straight wheel is used.

A large range of feeds and speeds, together with the angular adjustment of the table, makes this machine ideal in toolrooms for grinding flat, concave, or convex surfaces on dies, cutters, and gages, or for miscellaneous surface grinding. Many are used on straight production work for grinding piston rings, collars, dies, disks, and milling cutter and reamer blades.

The Blanchard intermediate-size **rotary surface grinder**, Fig. 37, has the abrasive wheel driven directly by the lower end of the vertical motor shaft. The rotating table also is mounted on the vertical shaft.



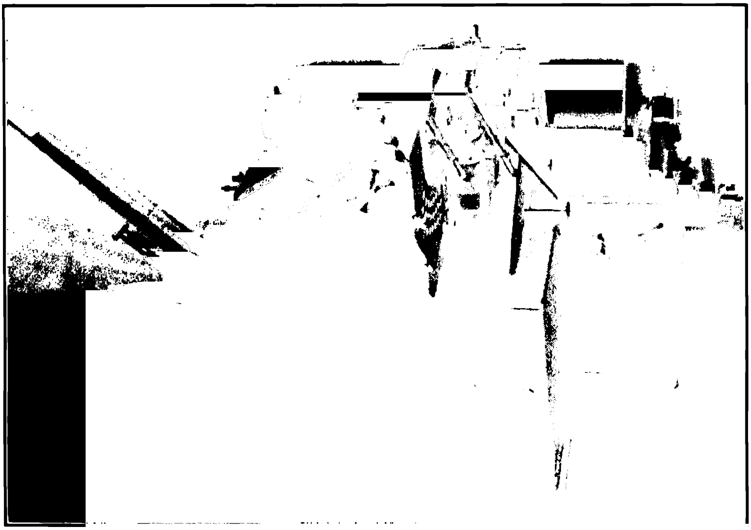
Courtesy Blanchard Machine Co.

FIG. 37. The No. 16 High-Power, Vertical-Spindle, Rotary-Table Surface Grinder Arranged for Direct-Motor Drive.

A one-piece, steel, magnetic chuck 26 in. diam. is mounted on the table to hold the work. A segmental wheel 32A 60-E 12 VBEP (Norton) is used for hard steel, 32A24-I8VBE for soft steel, and C24-118V for cast iron.

The table is shown withdrawn from beneath the wheel for loading. This machine is used on a wide range of production work and also on die and tool work. The work to be ground is clamped in work-holding fixtures or laid on the rotary magnetic chuck, while the table is being slowly rotated by means of foot pressure on the pedal at the front. The table is then moved forward to bring the center of the chuck just under the front face of the cup wheel, in which position it is rotated. The wheel head is then fed gradually down by hand or power until the desired size of work, as indicated on the gage, is obtained. The metal is removed by a series of shallow cuts over the entire surface of the work. When the correct size is reached, the downward motion of the wheel head is stopped, the wheel is raised at rapid traverse, and the table is moved out by the 4-handled wheel to the loading position where the work is removed.

The **double-spindle grinder,** Fig. 38, with built-in 15-hp motor drive operates the two 22-in.-diam. grinding disks in opposite directions at 1,200 rpm. The magazine and conveyor adapt the standard machine to the grinding of piston rings. The rough castings are shown stacked in the hopper at the left. They are carried by the belt conveyor to the chute which passes the rings in a vertical plane between the rubber rolls controlling the rate of feeding the rings between top and bottom guides diametrally across the face of the wheels. Wheel dressers of the rotating metal disk type are located on the forward end of the central lever which is rocked forward when the wheels are separated. Reeves variable-speed power transmissions are used to control the speed of the conveyor belt and rubber feed rolls. A roughing operation removes 0.010 in. from each side of 3½-in.-diam. ring cast-



Courtesy Hanchett Manufacturing Co.

FIG. 38. The No. 221 Double-Spindle Opposed-Wheel Grinder.

Set up with a magazine and conveyor for grinding cast-iron piston rings at the rate of 200 per min. No. C24-7LT2 Norton wheels of Bakelite bond are used for roughing. For semifinishing, 60L wheels are used. Wheel wear on the roughing operation is about 1 in. of wheel per 600,000 to 1,000,000 rings.

ings as they are fed at the rate of 75 fpm between the wheels. A semifinish grinding operation on a similar setup removes 0.003 in. from each side. From 0.001 to 0.002 in. is left for finish grinding, one at a time, on a rotary table grinder in which approximately 15 sides per min are ground in each of the roughing and finishing operations, with one operator running up to three machines. Revolving drums or reciprocating fixtures of many types are used to carry the work across the face of the disk wheels.

CUTTING FLUIDS FOR GRINDING

An emulsion of soluble oil and water is inexpensive and satisfactory for general grinding. The life of the wheel and the production rate are increased by using appropriate cutting fluids. A large quantity should be circulated. For steel, 1 part of soluble oil to 40–50 parts of water is recommended. When grinding cast iron, 1 part of soda solution of about 25 per cent concentration may be added to the above emulsion to advantage. Two parts of kerosene are sometimes added to the emulsion in lieu of the soda when grinding aluminum. The kerosene tends to keep the wheel from loading and prevents glazing. When grinding fiber, paraffin oil is best; but when grinding rubber, carbon, Celluloid, casein, etc., plain hydrant water may be used and thrown out in order to remove the material held in suspension. A light mineral oil is used on thread grinders where the best surface finish is required. Special cutting fluids are used in honing and lapping, as discussed under those subjects.

TOOL AND CUTTER GRINDING MACHINES

Grinders for specific purposes have been illustrated in the several chapters for grinding drills, taps, single-point tools for lathes, planers, and shapers, milling cutters, and broaches.

POWER, VOLUME RATIO, AND SURFACE QUALITY IN CYLINDRICAL GRINDING

For an investigation of cylindrical grinding, a No. 2 Cincinnati cylindrical grinder was equipped with a 7-hp d-c motor to drive the 14-in.-diam. and $1\frac{1}{2}$-in. face wheel, a 2-hp d-c motor for traverse, and a $\frac{1}{2}$-hp d-c motor for work rotation to make available any desired combination of wheel and work speed, traverse, and in-feed for any type of wheel, grinding compound, and material. A recording wattmeter was connected to the wheel motor so that tare, gross, and net power could be recorded. Wheel wear; metal removal; surface finish in microinches, r.m.s.; net power; and surface temperature of the work were obtained from each test. Volume ratio (Vr) equals the volume of metal removed (Vm), divided by the volume of wheel wear (Vw).

> For example: in one series of tests an SAE 52100 steel bar (2 in. in diam. and 10 in. long) hardened to 63 Rockwell C was ground at 6,500 fpm with a depth of cut for each traverse of 0.001 in., a table feed of 26 in. per min or 0.081 in. per rev of the work, with the work speed of 320 rpm, using a water-soluble oil of 5 per cent by volume in water for each of two wheels. One wheel was A80J6V10 and the second was A150J6V10. The volume ratio was 70.5 for the 80-grit wheel and 52.6 for the 150-grit wheel. The hp_n was 2.84 and 1.85, respectively, the unit hp_n was 18.9 and 12.4, and the percentage increase in hp_n for 60 traverses of the work was 38 and 6 per cent, respectively. The temperature increase on the work surface over the initial temperature was 16° and 12°, and the surface finish with no spark out was 28 and 29 microinches, r.m.s., respectively. This shows the two wheels to be nearly equivalent so far as surface finish and temperature increase are involved, but the 80J wheel had a greater volume ratio while the 150J wheel had the lower hp_n and unit hp_n.''[a]

The unit net horsepower at the motor, uhp_n, when grinding a hard and soft steel and a hard and soft cast iron at each of several combinations of depth of cut and feed, is shown in Fig. 39. A grinding compound of 5 per cent soluble in water was used at 5 gal per min at 70° F. For these wheel and grinding conditions, the grinding was too heavy for cuts of 0.003-in. depth and 0.162-in. feed. The curves show, however, that the unit net power is lower for the heavier cuts with 7 as a practical minimum.

The unit net power hp_n, when grinding the above two steels and irons and an SAE 52100 steel at 63 Rockwell C, with wheels of the above size of various grains and grades at 6,500 fpm grinding speed, 250 fpm of 2-in.-diam. work, 0.001-in. depth of cut and 0.081 ipr feed, and the water-soluble solution of 5 per cent, is as follows: for an A46–J6–V10 wheel, the unit hp_n was 17 for 20,000 psi cast iron, 18.5 for 40,000 psi cast iron, 20 for SAE 1020 steel at 131 Bhn and SAE 1045 steel at 260 Bhn, and 24.5 for the hardened SAE 52100 steel at 63 Rockwell C. An A46–M6–V10 (slightly harder) wheel gave about the same results as did an A60–J6–V10 and A60–M6–V10 wheel, although the net power per cubic inch per minute for the soft iron increased to 25 for the 60–M wheel. The lowest unit power values were obtained for an A150–J6–V10 wheel with a range from 7 for the soft steel to 13.5 for the hardened SAE 52100 steel.

The performance for these cutting conditions was best on the SAE 52100 steel when using an A150–O6–V10 wheel at 6,500 fpm rather than at lower speeds. At this speed (with no spark out) the surface finish in microinches, r.m.s., was 35 at 4,500 fpm, 32 at 5,500 fpm, and 28 at 6,500 fpm. The surface finish is best for the harder grades of this grit and at the highest speed. It becomes poorer at heavier cuts for all metals.

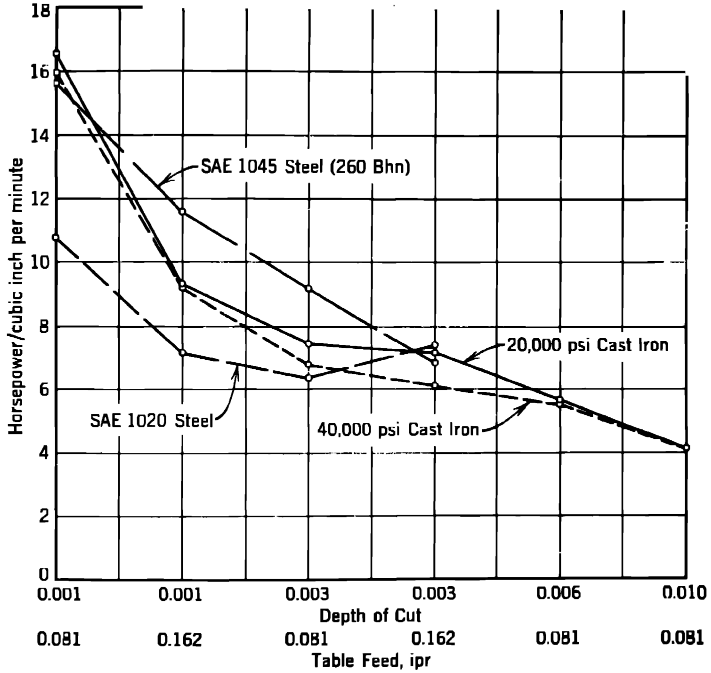


FIG. 39. Curves Showing Unit Net Horsepower at the Motor When Grinding One Soft and One Hard Steel, and a Soft and Hard Cast Iron for Each of Several Combinations of Depth of Cut and Table Feed.

The grinding wheel A80-M6-V10 operated at 6500 fpm, the work at 320 rpm, while cooled with a water-soluble compound of 5 per cent in water at 5 gal per min at 70° F. The wheel face was 1½ in., its diameter was 14 in., the work was 2 in. in diameter and 10 in. long, and the wheel cleared the work at each end.

In general, for good results from these tests, a surface quality of 25 microinches, r.m.s., a unit net horsepower of 13, and a volume ratio of metal removal to wheel wear of 50 should be obtained.

Values of uhp_n may be computed for an A150–M6–V10 wheel grinding hardened SAE 52100 steel with a wheel speed of 6,500 fpm and work speed of 2 in. diam. at 320 rpm at various depths of cut and feed, as follows: Given $uhp_n \times f^{0.35}d^{0.4} = 0.382$, when $d = 0.001$ and $f = 0.081$, $uhp_n = 14.4$.[11a]

HONING

Definition of Honing

Honing, as applied to **small tools or flat surfaces,** is an abrading operation in which a honing stick or stone is used. Small natural stones known as " Pike " or " Arkansas " stones have been used for years to whet or sharpen scythes, knives, razors, etc., by hand. Manufactured " India " oilstones were developed to supplement or replace the stones of natural abrasive rock. Small " India " oilstone wheels are used in more delicate grinding operations, such as grinding small watch parts.

Numerous shapes and sizes of abrasive sticks and bricks for hand and machine use are now manufactured by bonding silicon carbide, aluminum oxide, and diamond abrasives. Abrasive bricks 2 in. by 3 in. by 6 in. of 24-grit silicon carbide, grade Q, often are used by hand for smoothing large gray-iron castings where portable grinding equipment is not available. It is common practice to hone the cutting edges of cutting tools such as drills, reamers, and single-point tools, after sharpening or periodically during use, by a hand operation using, for example, vitrified sticks of C150–N6 for roughing and C400–L for finishing. To remove hard scales from glassware molds and metal dies after heat treating, and for many similar purposes, sticks varying in size from ¼ to 1 in. sq in lengths from 3 to 8 in. are used. For roughing, the Norton Co. recommends silicon carbide, vitrified sticks of 120–180 grain, J to L grade; for intermediate stages 320–400 grain and H grade; and for the final surfacing 600 grain of G grade. Sticks equivalent to those mentioned are made by many manufacturers, having sections round, square, rectangular, triangular, knife-edged, tapered, etc.

Honing, as applied to finishing external and internal **cylinders, bores, and tubes,** is an abrasive operation in which a honing tool equal in diameter to that of the bore is used as described below.

Types of Hones

Just a few years ago cylinders of internal-combustion engines, compressors, etc., were finished by boring or reaming. Later **internal grinding** machines were used to finish the surface. To remove the fuzz and high spots left by grinding and to give a better wearing surface, a lap of soft material, such as wood, lead, or cast iron, was used next in connection with a fine abrasive in oil. This lap was reciprocated and rotated in the cylinder. It removed very little metal and required considerable time, so laps were replaced by honing tools built up of bonded abrasive sticks of square or rectangular sections applied against the work with low unit pressure and speeds over a large area of contact. A combination of rotating and reciprocating motion is employed, as illustrated in Fig. 41. **Hones** are most generally used after fine boring or reaming to get the bore round and straight with a suitable surface finish. Cylinders from ⅛ to 42 in. diam. are honed for such work as guns, motors, compressors, and pumps, and many other parts.[5]

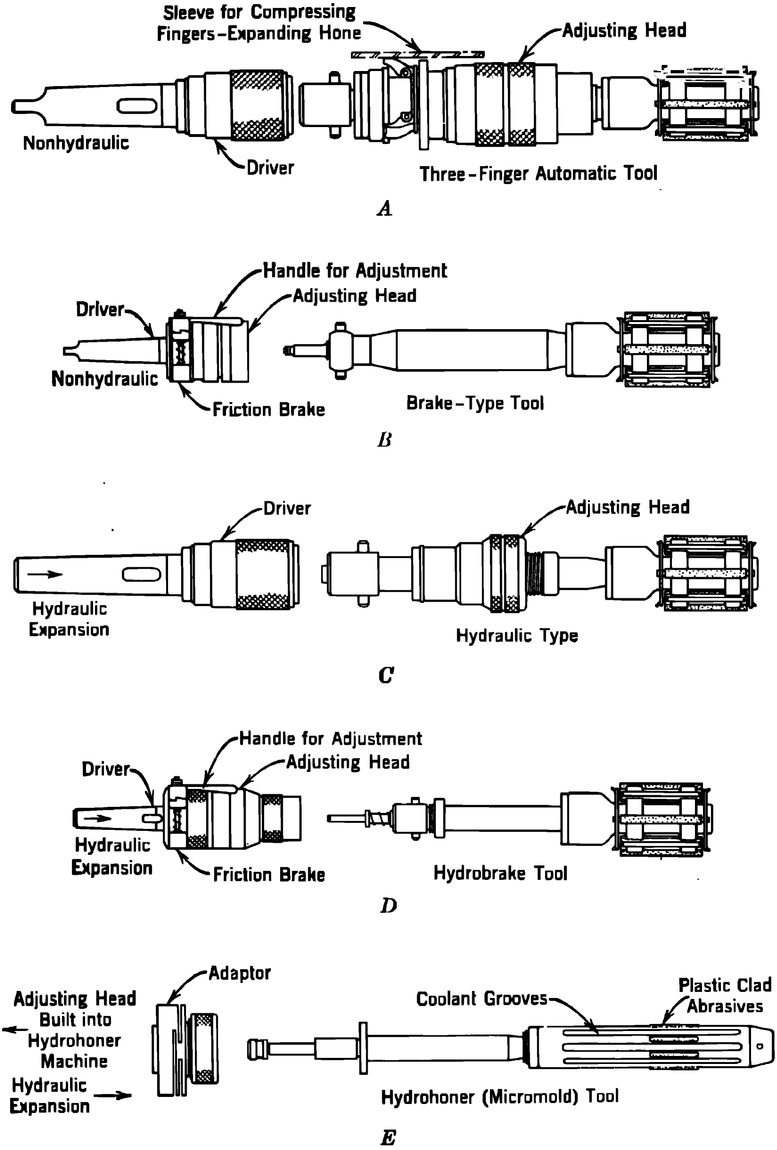
Hones with six stones have been found to operate satisfactorily under most conditions. Four stones are often used for diameters below 3 in. More may be used in larger sizes to remove metal faster or to bridge large port openings. One stone and two plastic wipers are often used on small work. The abrasive stones are usually mounted in metal holders in a true relative position in the hone shoe. The size of the hone is controlled by supporting the shoes solidly on a central longitudinally adjustable cone. These tools will remove a taper from a cylinder, grind it to the form of a true circle, and to final dimensions within one or a few ten-thousandths of an inch. Although this operation is usually referred to as honing, the tools are substantially solid segmental grinding wheels of a compensating and adjustable type. The expanding cone or cones make a solid backing for the stones. Some hones are supported rigidly in the machine spindle, Fig. 41, and the work is held in a free floating fixture. Others are free floating in the spindle, and the work is held rigid, Fig. 42.

Hones are built in a wide range of sizes and also in forms for through-hole and blind-end honing, as well as tandem hones.

Tandem hones, consisting of a double row of honing stones with an expansion cone for each set of stone holders, are generally used for large and long cylinders. They are faster cutting and have a greater tendency to produce straight bores.

Hones may be expanded to overcome the wear of the stones and the removal of metal, manually by ratchet, by three fingers, Fig. 40, by a friction brake, or hydraulically.[16]

A common type of **spring-expanded tool** is the three-finger automatic honing tool shown at *A* in Fig. 40. This type has been used extensively in the automotive industry for honing cylinder bores, but is now largely replaced by a tool with a positive controlled increment feed. As the hone enters the bore to be honed, the three fingers on the upper portion of the drive shaft enter a guide bushing located in the fixture above the bore. The bushing forces the fingers together,



Courtesy Micromatic Hone Corp.

FIG. 40. Various Types of Honing Tools.

A, **The three-finger automatic expanding tool; *B*, the brake-type tool; *C*, the hydraulic expanding tool; *D*, the hydrobrake tool; *E*, the micromold tool.**

thus compressing a caged spring. This causes the expanding cone to advance and force the abrasive stones against the wall of the bore. The friction of the rotating fingers against the stationary sleeve causes a drag on the tool, so the honing stones expand continuously as the stones wear or the bore is enlarged. The tool is fitted into the Morse taper shank of the machine spindle. The upper part drives the lower part through a universal joint with a bayonet lock. The **brake-type tool,** *B* in Fig. 40, is mechanically expanded by means of an adjusting head built into the driver. The cone rod is screwed into the tool drive shaft, and the square end of the cone rod fits into a gear in the adjusting head. A hand-operated friction brake slows down the rotation of the cone rod in relation to the drive shaft, thereby advancing the cone by the action of the threads. **Hydraulic tools** such as that shown at *C*, Fig. 40, are used on machines equipped with a hydraulic system. They are best suited for honing hard parts where high pressures are required to remove large amounts of stock. An adjusting head which is part of the drive shaft is also used on this type of tool to compensate for stone wear. **Hydrobrake** tools illustrated at *D* are a combination of the brake and hydraulic types, incorporating features of each. The tool can be expanded either hydraulically or by means of the friction brake while the tool is cutting. The micromold tool, *E*, is made by molding the abrasive into a plastic holder, reinforced underneath with a steel grip. This molded stick with stone side open replaces the conventional shell, stone holder, and intermediate expander. The bottom surface of the mounting is tapered to the same angle as the feed-out cone of the honing tool. The plastic wears with the abrasive, thereby preventing spalling of the edges of the abrasive.

A honing tool of the **rigid** type, that is, fixed in the spindle, is shown in the small horizontal Hydrohoner illustrated in Fig. 41. The initial expansion of the tool is caused by high-pressure oil entering the top of the cylinder in the tool, thus exerting a direct thrust on the hydraulic piston. This thrust is transmitted through the spindle and adjusting head to the cone rod. This expansion takes place at the bottom of the first stroke. The piston is locked in this position until the end of the cycle by a pin which enters a bayonet lock. Thus the tool can be collapsed only by hydraulic pressure applied to the underside of the piston. The expansion of the tool during the honing process is accomplished by rotating the adjusting sleeve either manually or hydraulically.

Types of Honing Machines

Honing machines are made in various types and sizes. The object of each is to rotate and reciprocate the hone. The machines may be classified as follows:

1. Service (job-shop) honing machines.
   (a) Portable electric-drill drive.
   (b) Portable self-contained machine.
   (c) Combination boring and honing machine.
2. Single- or multiple-cylinder production honing, Figs. 41 and 42.
3. Horizontal, vertical, or angular spindle.
4. Manually or automatically operated.
5. Large-cylinder honing.
6. Long-tube honing.

Most modern production honing machines reciprocate the tool hydraulically so as to give uniform traverse speed, a cushioned reverse at each end, and flexibility as to operating cycles.

A **horizontal honing machine** for high production of small parts is shown in Fig. 41. The work held in a full, floating fixture is mounted on the table, which rapid-traverses to the hone hydraulically, then reciprocates the work over the hone until final size, when the table returns to starting position. When the work reaches the hone, the hone starts to rotate and oscillate rapidly from $\frac{1}{16}$- to $\frac{1}{4}$-in. length of stroke. One belt on the driving motor rotates the hone and a second belt drives the swash plate to give the rapid oscillations. The hone is expanded hydraulically.

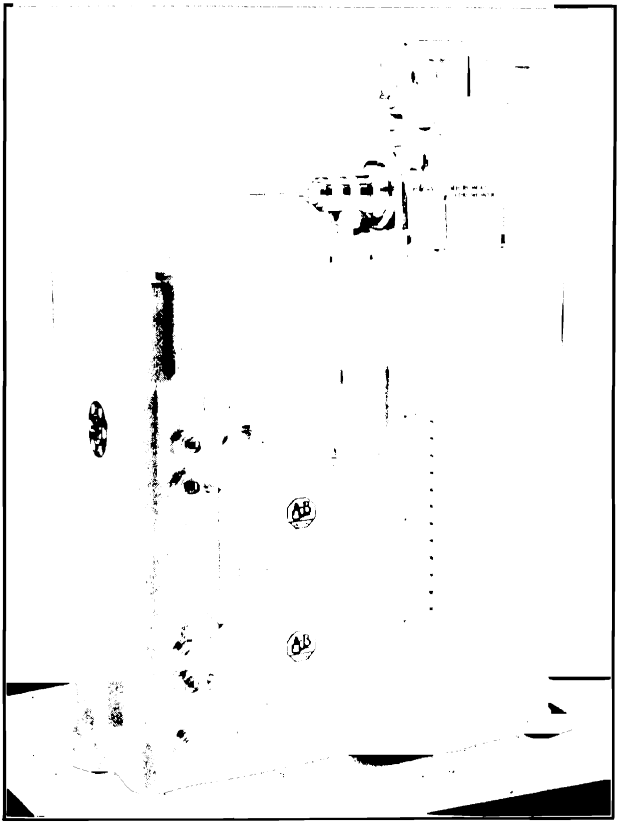
The Micromatic Hone Co. makes machines with one spindle which hone one piece at a time, other machines with two spindles which hone two pieces at a time, and still others for finishing a part in a two-spindle, three-station machine in three successive steps: load, rough, and finish. The large ends of automotive connecting rods are honed two at a time in a two-spindle machine, removing 0.003–0.004 in. of bearing metal in a 45-sec cycle, and held within 0.0005 in. in diam.

Inner races for ball bearings are progressively honed in three steps with 0.009–0.014-in. total metal removal on diameter at 500 pieces per hr and held to a folerance of 0.0001–0.0003 in. Each hone is of the Micromold (sticks in plastic) type with Microsize control.

The plastic wears with the stones to exact hole size. As the hole is enlarged, the plastic fits a sintered-carbide or Norbide ring gage immediately above the work. Friction twists the gage ring and makes an electrical contact to stop further processing.

Some machines employ the air-gage principle to stop the honing operation when the correct size of work is reached.

The Sunnen Products Co. makes a **small honing machine**, the spindle of which rotates and expands the hone mechanically, while the work is reciprocated and held on the honing unit by hand. This

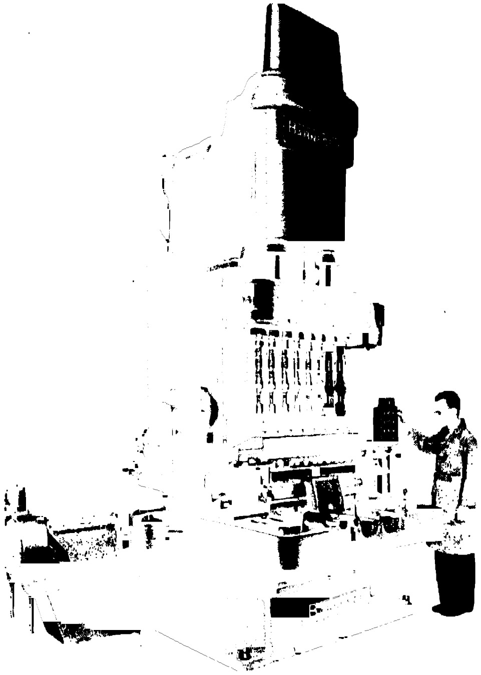


Courtesy Micromatic Hone Co.

FIG. 41. The Micromatic Horizontal Hydrohoner for Small Work.

This has a horizontal spindle, the left end of which carries the hydraulically expanded honing tool, which rotates and reciprocates rapidly up to ¼ in. maximum. The work is held in a full floating fixture mounted on the table, which is reciprocated hydraulically.

will hone sizes from ⅛ to 2⅝ in. in diam., and units can be interchanged in less than 1 min. Accuracy of 0.0001 in. and closer can be maintained while surface finish can be held from 2 to 6 microinches, r.m.s., on hardened steel parts. Honing units are made up in various sets of selected sizes. The honing tool consists of a holder for one stone and two plastic work guides to give a three-point support in the hole. Four speeds of 250, 410, 600, and 820 rpm are available at the spindle, which is driven with a $\frac{1}{3}$-hp motor. This machine is fast and accurate for small work for both large and small quantities. In honing cast-iron bores with roughing stones, a surface finish of 21 microinches, r.m.s., can be obtained; with finishing stones, $4\frac{1}{2}$ microinches, r.m.s. When honing hardened steel with roughing stones, the surface measures $7\frac{1}{2}$ microinches, r.m.s., and with finishing stones it is reduced to $1\frac{1}{2}$ microinches, r.m.s.



Courtesy Barnes Drill Co.

FIG. 42. The New No. 320 Vertical Multiple-Spindle Hydraulically Reciprocated Honing Machine Equipped with an Eight-Spindle Fixed Center Auxiliary Head for the Operation of Micromatic Hydraulic-Type Honing Tools and Hydraulic Clamping Fixture Holding an Eight-Cylinder Motor Block.

The rotor conveyor in the table is a part of the conveyor line, so that cylinders are brought to and taken from the machine with the greatest of ease. The Barnes magnetic chip separator is shown at the left.

The Barnes Drill Co. No. 320 **multiple-cylinder, vertical, hydraulic honing** machine is shown in Fig. 42. This machine is provided with a hydraulically reciprocated head and eight hydraulically operated

Micromatic honing tools. The clamping of the cylinder blocks in the fixture is also accomplished hydraulically. The spindle-drive motor is 30 hp to provide peripheral speeds to the hones of 200–220 ft per min. A 15-hp hydraulic-drive motor reciprocates the hones. The cutting-fluid pump is driven by a ½-hp motor. The machine is provided with a magnetic chip separator which removes all ferrous material from the cutting fluid. The cutting fluid flows from the chip pan of the machine to the rear of the separator. It then flows underneath a cylindrical drum to the front, where it is discharged into the base of the honing machine for recirculation. As the cutting fluid flows under the drum, which is rotating to oppose the flow, permanent magnets on the inside of the drum cause the ferrous chips to adhere to the drum to be carried over the top to the front, where they are scraped off and deposited in a chip pan for disposal. One machine uses 150-grit stones for rough honing for sizing and accuracy, while the second machine, using 500-grit stones, finishes the bore to within 0.0005 in. of tolerance to a surface finish of 2–8 microinches, r.m.s.

Honing practice: Cylinders are often finished in two honing operations, one in which comparatively coarse honing stones are used for rapid removal of metal, and a second employing fine-grained stones to provide a smooth surface.

On a well-reamed or finish-bored cast-iron cylinder, a hone can quickly finish it to an accuracy within 0.0005 in. by operating at rotating peripheral speeds of 110–200 fpm. The stroke speed or spindle travel for cast iron should be from 50 to 110 fpm. For honing soft-steel cylinders, from 0.0015 to 0.002 in. can be removed by the hone while it is operating at a peripheral speed of 50–110 fpm and a spindle reciprocating speed of about 20–90 fpm. The length of the cylinder, plus the overrun of the hone at each end, minus the length of the stone in the hone, determines the length of the stroke. The ratio of the stroke cycles to revolutions per minute is about 1 to 3½.

The average practice of eight large automotive plants using Micromatic hones follows: In a cast-iron cylinder diameter of 3 in., 0.0015 in. of stock is removed in 10–15-stroke cycles with a tolerance of 0.0005 in. out of round and taper, with a surface quality of 12–20 microinches, r.m.s., honing about 90 blocks per hr, using a hone with six stones of C 150 M. The work is flooded with kerosene, and about 700 holes are produced per set of stones. In some instances, to secure a better surface finish of 2–8 r.m.s., a second honing operation is performed with 500-grain stones. Stones of medium grain of 320 grit and on the soft side are used in single-operation honing.

Softer stones are used on harder metals. High reciprocating speed causes faster cutting. Finer grit sizes and more multidirectional action between stone and work, longer run-out time after reaching size, and higher speed of rotation will improve the finish (*Machinery*, June, 1948, p. 145).

Honing is applied successfully to relatively small bores in which the **length is less than the diameter.** The crankpin hole in connecting rods for small internal-combustion engines, rocker arms, roller-bearing races, gears, etc., represents this type. A special type of hone is rigidly guided vertically and the work is allowed to float, whereas the usual practice is to hold the work and allow the hone to float. The Ford connecting-rod main bearings are honed four at a time in this manner in a fixture holding four rods, one above the other displaced angularly, supported on a fixed pin in the piston-pin hole. The larger end located under the hone floats. These bores are well below 0.0003 in. for roundness, straightness, and diameter size, being much less than could be obtained by internal grinding or diamond boring (*Iron Age*, July 21, 1932, p. 98).

Large-diameter bores are honed in horizontal or large vertical machines. Diesel-engine cylinders 14 in. in diam. by 54 in. long are honed on a vertical honing machine of the hydraulic type equipped with heavy-duty hones, in 10 min floor to floor, removing approximately 0.004 in. of stock.

Long bores, tubes, and guns are honed successfully. The machines are usually of the horizontal type with the hone reciprocated hydraulically.

Cutting fluids: Kerosene and mineral spirits have been found to be good coolants to use in connection with honing cast iron or hard steel. Sulphurized mineral-lard oil or lard oil and kerosene gives better results when honing soft-steel cylinders. A water solution has given excellent results. Equal parts of kerosene and red engine oil are used on babbitted bearings. A copious and continuous supply of the coolant should be circulated, and it should be settled and strained before being recirculated to free it from minor particles of metal and dirt. Magnetic chip separators are being used to separate the ferrous chips from the cutting fluid before it is recirculated to the tools.

LAPPING

Definition of Lapping

Lapping is a process of producing extremely accurate and smooth surfaces by means of a charged lap, or a lap and fine abrasive compound. Lapping may be done by hand or by machine. In some machines so-called lapping operations, abrasive paper, and solid fine-grain abrasive wheels are used at slow speeds as described below. In general, the purpose of lapping is to reduce the minute hills and valleys left by machining or grinding operations. In tool making, or in the production of close-fitting running parts, where accurate duplication or fitting of parts is necessary, lapping reduces the chance for wear by providing a more uniform bearing surface and insures the maintenance of dimensional standards. In optical work, lapping is resorted to for the purpose of obtaining accurate dimensions, as well as a finish that will not interfere with light waves.

If a part is to be lapped to final accurate dimension, a mating form of a softer material, such as soft close-grained cast iron, copper, brass, or lead, is made up. The surface of the lap is charged with a fine abrasive, such as silicon carbide flour; or a small amount of abrasive mixed with lard oil, olive oil, machine oil, kerosene, alcohol, grease, or a special manufactured lapping compound is placed between the two surfaces while they are rubbed together along an ever-changing path. Hand lapping requires considerable skill, time, and patience. No more than 0.0002–0.0005 in. should be left for removal by this method.

Surface plates, rings, and plugs are common forms of laps. The seating of valves in a gas engine is a common illustration of lapping, the valve itself serving as the lap. Crocus or lime is used in lapping bronze or brass, or with a cast-iron or lead lap for fine work on steel. A soft cast-iron disk with its surface impregnated with diamond dust is rotated in a machine for lapping sintered-carbide tools to obtain a keen cutting edge. Boron carbide (B_4C) or "Norbide" 320 and 600 grain is used for rough and finish lapping gages of Stellite, high speed steel, chromium plate, and sintered carbide. In general, copper and soft-steel laps cut faster than cast iron, but cast iron retains its form better. A surface quality of ¼–1 microinches, r.m.s., is obtained in this manner.

To produce a true surface plate, for example, three such plates are required. Two of them are first scraped or lapped together with a thin film of fine abrasive compound between them. One of the two is then scraped or lapped with the third, the third with the second, etc., until the desired condition is obtained.

Machine lapping, Fig. 43, is used widely for fine finishing of gears, ball- and roller-bearing races, crankshafts, piston pins, machine bearings, gages and measuring instruments, and hundreds of other parts where accurate dimension, the finest finish, or a long-wearing surface is required. Commercial lapping compounds are now available, in various grades and grit sizes, consisting of a fine abrasive held in an emulsion, oil, or grease.

Types of Lapping Machines

Lapping machines are made in a variety of types and sizes for large-quantity production, but standard machines may be adapted to lapping operations in the job shop or toolroom where the quantity does not justify the specialized machine. Cylindrical plug gages, toolmakers' buttons, pistons, crankshafts, as well as the sides and ends of parallel gage blocks, and teeth of gears are classes of work which may, for the purpose of accuracy and better finish, require lapping. Cylindrical work may be lapped in the job shop by rotating the work in a lathe or drill press and reciprocating the lap over the work in an ever-changing path. A charged lap may be used with a light oil to keep the lap from drying and to keep the work cool, or a fine abrasive in an oil may be applied periodically to the work or lap. Small flat surfaces may be lapped by holding the work against a rotating disk, or the work may be moved by hand in an irregular path over a stationary faceplate lap.

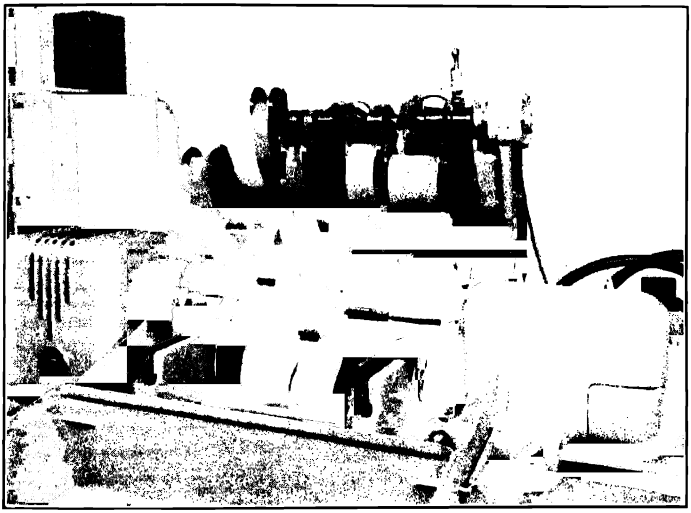
Courtesy Norton Co.

FIG. 43. Machine Lapping Simultaneously Two Concentric Diameters of an Air-Hammer Piston by Means of Special Cast-Iron Laps.

A tolerance of ±0.0001 in. and a surface quality of 1-4 microinches are obtained.

When many parts are to be lapped to true shape and close limits, special machines and devices are employed. Usually only a few ten-thousandths of an inch are removed so that lapping invariably follows finish grinding.

In the **crankshaft polishing machine**, Fig. 44, a short reciprocating motion is imparted to the crankshaft during the lapping operation to avoid lines in a diametral plane and to improve the finish. The first machines were equipped with cast-iron laps and used a lapping paste of fine abrasive in kerosene and lard oil. Later, bonded abrasive sticks were used with a lubricant. The latest machines have opening forms which hold a fine abrasive paper or cloth, and the lubricant is pumped directly to each set of laps. Cylindrical work, such as gages, shafts, or production parts, can be lapped more accurately on machines than by hand. It has been shown that gages lapped mechanically wear longer than those lapped by hand. Not more than 0.0005-in. stock should be left for lapping, and surfaces of ½–4 microinches, r.m.s., are obtained.



Courtesy Norton Co.

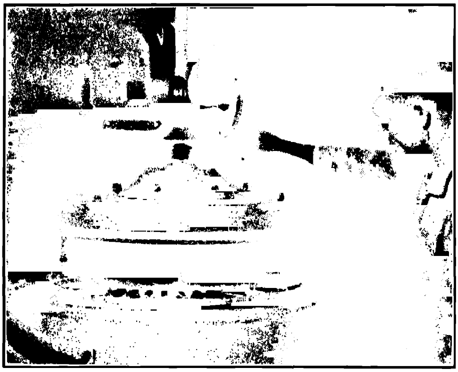
FIG. 44. A Close View of a Two-Throw Crankshaft Mounted on Centers of the Norton Type No. 30, Crank-O-Lap Machine.

The lapping arms support the abrasive strip. Using 320-grit paper, 40–60 rough-ground shafts per hour are finished to a surface quality of 5–8 microinches, r.m.s.

Another type of **lapping machine** for circular or flat work consists essentially of two opposed lapping surfaces maintained on vertical spindles, Fig. 45. Bonded abrasive circular wheels are used as laps. Both are rotated, but in opposite directions, at speeds not to exceed 700 fpm. The upper wheel "floats" while lapping, but is clamped while being trued. Variable spring pressure is applied to the work through the upper lap. Various types of work holders are used.

Disk holders have perforations of a shape to hold solid cylindrical or flat pieces, while spiders, as shown, are used to carry hollow cylindrical parts. These work holders, driven by the lower central shaft, are eccentric with the upper and lower laps, and control the path of the work so it rolls and slides freely in an ever-changing path between the laps.

The upper lap is elevated to show the spider type of work holder. Pins are mounted around the periphery at a slight angle from the radial on which the hollow cylindrical piston pins are carried. Pins are rough lapped by removing 0.003 in. of metal on the diameter with C150-N-5L wheels, and finish lapped by removing 0.0001 in. with C400-N-5L wheels. The production rate of each operation is 550 pins per hr. In use a generous supply of lapping liquid should be allowed to flow on the work between the laps to wash away all loose particles and prevent scratching, provide a good finish, and keep the work at a uniform temperature. A small amount of commercial soap flakes mixed in water serves this purpose. Kerosene also is used.



Courtesy Norton Co.

FIG. 45. The No. 15C Lapping Machine Arranged for Lapping Cylindrical Steel Piston Pins to a Tolerance of 0.0001 in. and a Finish of ½-4 Microinches.

The cast-iron laps are widely used. After being charged, they are used without added abrasive until cutting stops. At times lard oil, olive oil, or kerosene is applied to the laps in small quantities to keep the lap faces moist. The lapping faces must be true planes. The metal laps are kept true by allowing them to run against each other for a few moments each day. While doing so, the upper lap should be moved back and forth across the face of the lower lap. A small amount of fine abrasive mixed with oil should be spread on the lower lap when truing. The faces of the cast-iron laps are serrated. This makes it easier to remove the work after lapping and provides a storage space for oil and abrasives. In this way, plug gages may be lapped to size, plus or minus 0.00002 in., but a roughing and finishing operation removing from 0.0003 to 0.0005 in. would be desirable. Flat master gage blocks are made on machines of this type under very carefully controlled conditions.

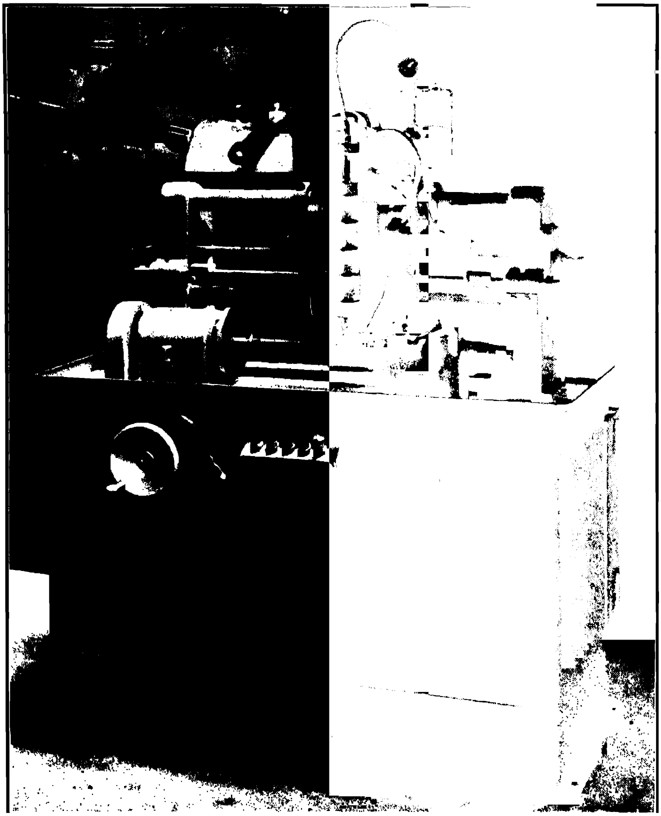
SUPERFINISHING

Superfinishing is a process of finishing parts by the use of bonded abrasives operating at low speeds, low-unit pressures, variable multimotion, and proper lubrication. By this process, size within a few millionths of an inch may be obtained with a surface smoothness having variations less than 1 microinch. Abrasive wheels and sticks having aluminum oxide grains, ranging from 100 to 600, are resinoid bonded to produce relatively soft grades. The speeds for superfinishing range from 300 to 1,300 fpm and are higher than those of lapping and honing, but less than those of grinding. The motion between the stone and work is varied in many directions so that no single abrasive grain retraces its path. The pressure between the stone and work is very light, ranging from a few ounces, when the abrasive is brought into contact with the surface to be finished, to 20–30 lb as the abrasive action proceeds and the area between the stone and work increases. It is applied by spring or hydraulic pressure.

Only 0.0003–0.0004 in. should be removed by superfinishing, although up to 0.001 in. may be removed. Superfinishing simply removes the metal deformed by the previous operation so as to increase the surface area from numerous small peaks to a substantially flat surface; however, it does not correct error in shape.

Superfinishing machines are developed which resemble the lapping machine. They are used for cylindrical, flat, and curved surfaces of a wide variety. Because of the short operating time, the rate of production is high and the cost low. A typical superfinishing operation is illustrated in Fig. 46.

Scraping: Sliding metal surfaces of machines, such as the ways of lathes and planers, faces of crossrails, and columns of planers and milling machines, usually are scraped after machining in order to provide a better wearing surface for the two mating parts. The scraper for flat surfaces, as shown in Fig. 47, is made by grinding the end of a large file nearly square and smoothing the adjacent faces. Keen cutting edges are formed with which high spots of the metal surface are pushed off. In scraping curved surfaces, such as bearings, a narrow side-cutting scraper is used which resembles a triangular file bent upward at the end with the bottom surface ground slightly concave and the two sides smooth. Usually the high spots between two sliding surfaces are detected by first painting one, such as the shaft, with Prussian blue and then sliding them together, Fig. 48, and scraping off the spots showing blue. This procedure is continued until the spots are very numerous, indicating that the surface in general consists of many smooth elevations and small shallow valleys which retain the oil.

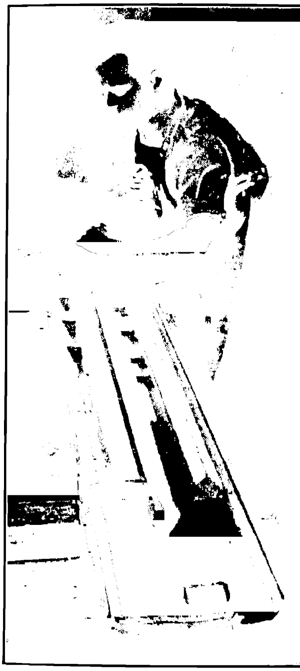


Courtesy Gisholt Machine Co.

FIG. 46. A Gisholt Model 51A General-Purpose, Cylindrical Superfinisher Set Up for a Routine Job on an Impeller Shaft.

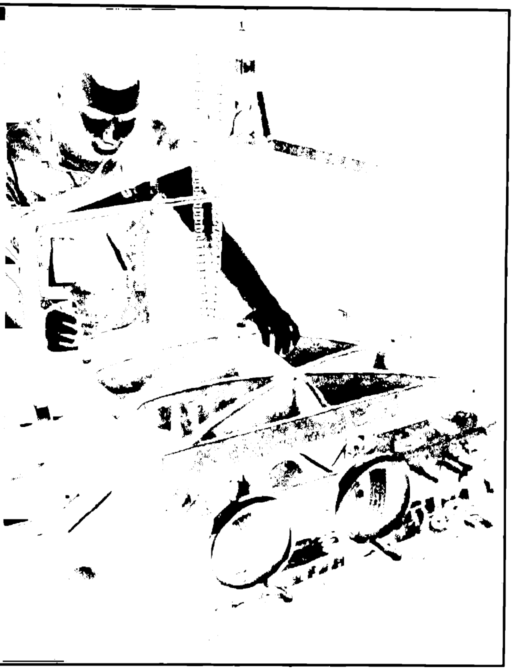
The surface quality will be from 2 to 3 microinches, r.m.s., removing from 0.0001 in. to 0.0004 in. to bring the part to size. The application of a single stone and the cutting oil applied to superfinishing a pinion shaft are shown in the insert.

Rolling: In the manufacture of some small cylinders of soft metal, cast iron, and hard steel, the final surface is prepared by a rolling operation. This may follow diamond boring or finish reaming. The surface so prepared in cast iron consists of fine particles of the metal imbedded in the wall. It has been found not satisfactory for a reciprocating motion, unless suitable material is used and proper application of the process is made, as crushed particles become loose when subjected to wear. For example, a cast-iron compressor cylinder of $1\frac{1}{4}$-in.-diam. bore and $3\frac{1}{2}$ in. long is first diamond or tungsten carbide bored to 0.0006 in. from size, after which it is rolled and burnished to



Courtesy DoAll Co.

Fig. 47.



Courtesy DoAll Co.

Fig. 48.

Fig. 47. The Final Hand-Scraping of the Flat and V Ways on the Underside of the Table of a Surface Grinder.

Such surfaces are hand-scraped to within less than one ten-thousandth of an inch of flatness and parallelism.

Fig. 48. The Two V Ways on the Bottom Side of the Saddle of a Surface Grinder Are Being Checked against a Master Way to Ensure Their Fitting Perfectly with the Male Ways on the Top of the Machine Base, on Which They Rest.

within 0.0002 in. of size, round, and straight. A rolling tool is used like a reamer. It consists of a number of small cylindrical pins rolling in the cylinder under alternating pressure produced by numerous longitudinal cams in the body of the tool supporting the rollers. As the tool rotates, the rollers are impinged thousands of times per minute against the cylinder wall.

Tumbling and Barrel Finishing

Tumbling in rotating drums has long been a process of cleaning and finishing components. Rough castings and forgings are often tumbled in large barrels with other smaller castings or heavy shot in order to remove flash, scale, sand, and surface dirt, before machining operations or other use.

Tumbling barrels are usually made of metal with renewable wood liners. Newer types have rubber or plastic linings. The barrels are of the tilting and horizontal types. The horizontal types run closed, rotating about the longitudinal axis. The tilting types may run with the end either open or closed. The angle of tilt may be adjusted for each job. Barrels rotate at speeds of 10–50 rpm, the smaller-diameter barrels having the higher speeds.

A relatively new technique known by some as Roto-Finishing has been developed in which finished parts from screw machines, stampings, small sand castings, etc., are tumbled in wet mixtures of limestone, granite chips, metal balls, or abrasive compounds to produce high surface quality and remove burrs and other surface imperfections. The deburring of parts in granite chips replaces in many instances those operations formerly done with polishing and buffing wheels, files, scrapers, and flexible-shaft tools. This method is much more time saving, as many parts can be tumbled at one time with little supervision. Roto-Finishing, as developed by the Sturgis Products Co., consists of four basic finishing operations, such as:

(*a*) Grinding for deburring with granite chips or grinding chips and compounds.
(*b*) Polishing with limestone or bright honing chips and compounds.
(*c*) Honing as under (*b*) with a special honing compound.
(*d*) Wet coloring, using various sizes of steel balls or other coloring media after any of the preceding operations.

Grinding, polishing, and honing as used in Roto-Finishing are not the same processes ordinarily thought of under these headings. The Norton Co. has developed an aluminum oxide tumbling abrasive usable on all metals and some nonmetals, such as plastics. In tumbling parts in this abrasive, a continuous cutting action with glazing is produced. This material is available in sizes from standard

No. 12 fine mesh to individual particles 1½–2 in. in length. The particles may be obtained in the rough-untumbled or smooth-tumbled condition. The untumbled material with sharp corners and edges cuts faster but leaves a rougher finish. Granite chips are available in sizes ranging from 1⅜ in. in the longest dimension down to 1/16 in., although most work is done in sizes from ⅞ in. down to 3/16 in. The size is determined so that chips will not lodge in holes, recesses, or slots of the parts being processed. Large chips cut faster by producing a rougher surface. Sometimes a combination of large and small chips is advantageous in deburring small slots and recesses, such as those encountered in steel stampings.

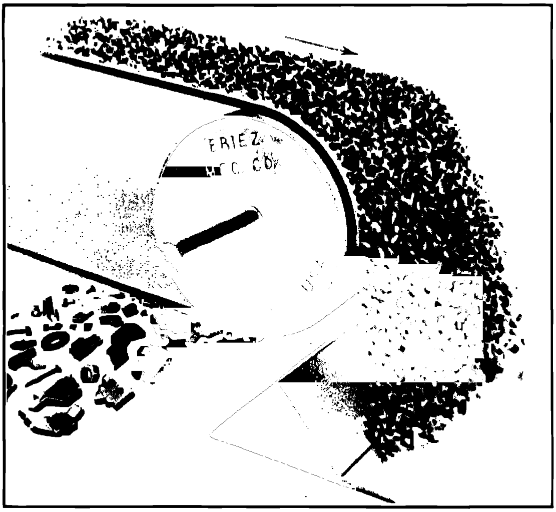
In general, it is possible to reduce a 60–40 microinch surface to 30–25 microinches by the use of granite chips and finer finishes down to 5 microinches with limestone chips. The compounds are specially prepared soap bases with varying alkalinity to produce the necessary lubrication of both chips and work, to provide the necessary abrasive action, and to give the desired finish. They also prevent the chips from becoming glazed.

The process of Roto-Finishing is to mix the work, abrasive, and compound in the rotating drum. The size of drum depends upon the volume of work to be tumbled. The abrasive is loaded into the barrel and thoroughly washed to remove sludge and extraneous material. The parts are loaded on top and leveled off, and water or compound is added to cover the entire mass 2 in. deep. The barrel should be from ½ to ⅔ full, and two to four times as much abrasive as work should be used. The door is clamped and the drum rotated from 20 to 24 rpm for 1–12 hr, as needed. The chips are then separated from the parts by emptying part of the load at a time onto a proper-sized screen which will either retain the parts and pass the chips or vice versa. In mass production the load is taken to a central separation unit, usually on conveyors, where the parts and chips are separated either mechanically or magnetically, as shown in Fig. 49. The parts are then rinsed in cold water and immediately are made noncorrosive.

If the grinding is followed by barrel honing, the work and abrasive are washed in the barrel, and the compound is changed to a wet honing compound and the rotation continued for another 2–3 hr. This produces a semilustrous finish on parts of zinc alloys, copper and aluminum alloys, and iron or steel. This finish honing will develop a finish in microinches, r.m.s., as low as 1.5 and adapt parts for bright nickel plating, anodizing, or painting.

Wet coloring, the last of the Roto-Finishing operations, follows either grinding, polishing, or honing, but steel balls or other highly polished media are used with the work load. The larger balls are used with the harder parts and special compounds for developing a high luster.

The average time for processing gray-iron sand castings is 1–2 hr; aluminum die castings, 2–3 hr; steel stampings, $1\frac{1}{2}$–3 hr; brass stampings and brass screw machine products, $1\frac{1}{2}$–2 hr. This operation deburrs and rounds the sharp edges of the parts and produces a surface finish ready for plating if desired. Small parts, such as small die castings and small stampings, may be handled on a volume basis by having one operator handling 4–8 machines producing 2,400 pieces per hr.



Courtesy Eriez Manufacturing Co.

FIG. 49. An Automatic Separator of Ferrous Metal Parts from Tumbling Stones after Deburring or Polishing.

The mixture is carried to the pulley on the belt. The pulley contains permanent magnets which cause the metal parts to be carried underneath, where they are separated from the magnets when the belt leaves the pulley. The stones and nonmagnetic material fall freely over the end into a separate tray.

The barrel finishing of a brass permanent-mold clothes hook, as reported by the Minnesota Mining and Manufacturing Co., is as follows: A barrel having two compartments each 32 in. in diam. and 20 in. wide carries a work load of 2,000 hooks, or a total load of 4,000 pieces. Natural flint stone 2 in. by $1\frac{1}{4}$ in. of 500-grit particles, with a liquid known as Honite compound No. 1, is used as the tumbling medium. Eight hundred pounds of stone are added to the load, 200 lb of which are used up in the operation. The total cost per piece amounts to $\frac{1}{10}$ of a cent for the 2-hr job. The cost of polishing on set-up wheels was $1\frac{1}{2}$ cents each piece.

QUESTIONS

1. Explain briefly what is meant by each of the following terms: grinding, polishing, buffing, honing, and lapping.

2. What are meant by natural abrasives? Name some of the natural abrasives.

3. What are meant by manufactured or artificial abrasives, and in what way are they superior to the natural abrasives?

4. What is meant by the following terms as applied to a grinding wheel: abrasive, bond, grain, grade, structure?

5. What are some of the bonding processes commonly used in making up grinding wheels? Explain briefly the purpose of each type of bond.

6. Indicate completely the specifications of a grinding wheel to be used for grinding single-point tools of hardened high speed steel.

7. Name some of the types of polishing wheels commonly used.

8. Name some of the kinds of buffing wheels in general use.

9. Explain what is meant in surface finishing by polishing, dry fining, greasing, cutting down, and coloring.

10. Explain the difference between dressing and truing a grinding wheel.

11. Explain the purpose of a cutting fluid as applied to grinding.

12. What are some of the buffing compositions generally used? As far as possible indicate their purpose.

13. Classify and indicate the purpose of each type of precision grinding.

14. What are the relative advantages of finishing cylinder bores for internal-combustion engines by boring, internal grinding, and honing?

15. Why are more than two motions between the stone and work desirable in honing?

16. When is a crankshaft lapping machine a crankshaft polishing machine?

17. What is meant by barrel finishing?

18. How is the rate of metal removal controlled in barrel finishing?

19. What abrasive processes are used to obtain a surface quality of 2–4 microinches, r.m.s.?

20. What is the general relationship between a surface finish and the tolerance on the dimension of the surface?

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CHAPTER XVI

PRESSES, PUNCHES AND DIES, AND FORMED PARTS

PRESSES

A **metal-forming machine tool** is a power-driven machine, not portable by hand, used to press, forge, emboss, hammer, stamp, draw, blank, or shear metal. Most of these machines, which are of a wide variety of types and sizes, work metal hot or cold. They comprise **presses** for cold working sheet metals, and extrusion presses, forcing presses, forging presses, shears, and hammers.

The press may be defined as a machine tool in which a bed or anvil, on which is mounted the lower part of a die, is approached by a ram carrying the upper die. The ram has a reciprocating motion in a line approximately at right angles to the bed, and is guided in the framework of the machine so that it may always move in the same path.

The press has gained a prominent place among machine tools for cheap and fast production of flat and formed parts in large quantities. By the adoption and use of suitable dies and fixtures, this tool is producing, at greatly reduced costs, high-grade and complicated parts from sheet metal, which were once produced from castings, forgings, or bar stock requiring subsequent machining operations.

CLASSIFICATION

Presses are used for a great variety of purposes. In order to handle the wide range of work now being done, many different types are required. Because of the variety of design, the wide range of application, and the overlapping of fundamental differences, a definite classification is difficult to make. Presses are designated as follows:

1. Source of power: manual, gravity or drop, and power.
2. Number of rams or slides: single, double, or triple action.
3. Construction for applying power to the ram: gears; screw; single or multiple crank; cam; toggle; knuckle joint; and pneumatic, steam, or hydraulic pressure.
4. Position of the ram: vertical, horizontal, or inclinable.
5. The use of the press: straightening, broaching, hot and cold forging, extrusion, sprue cutting, trimming, swaging, upsetting, blanking, shaving, punching, piercing, bending, drawing, embossing, coining and sizing metals, for molding plastics, and for general assembly work.

6. Design features of the frame: bench or floor type, inclinable, open back, straight side, arch, gap, adjustable bed, horning, wiring, shearing, trimming, sprue cutting, and gang.

The frames of presses may consist of one or more castings of gray iron or steel, or frequently, for the heavy-duty presses, the frame is held together by steel tie rods encased and shrunk in the columns. With the development of welding, frames are sometimes constructed by welding plates and structural shapes.

Most presses are actually a combination of the several classifications just referred to. There are, for instance, the single-crank, open-back, gap-type, direct-belt-driven, inclinable press shown in Fig. 4; the double-crank, single-geared, open-back, straight-sided press in Fig. 5; the knuckle-joint, embossing press, Fig. 7; and the toggle, double-crank, double-action, twin-geared, drawing press, Fig. 6.

MANUAL AND POWER MECHANICALLY OPERATED PRESSES

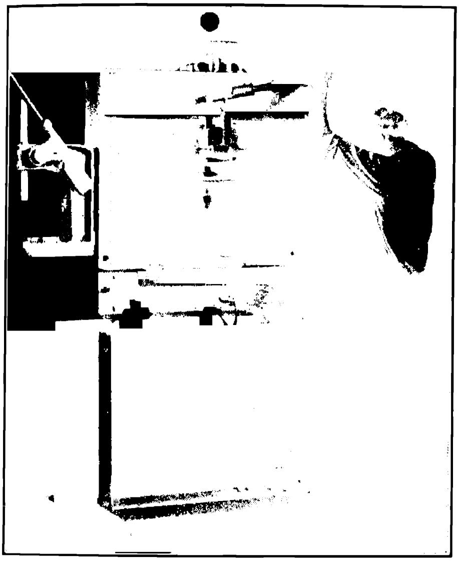
A **manually operated press** of the lever type of 3-ton capacity is shown attached to the left column in Fig. 1. It has a rack-type ram driven through reduction gears with the leverage of 112 to 1. These presses are often used to force mandrels into the bore of work so it can be mounted between the centers for machining. Foot-pedal presses of this type are often used for light assembling or straightening work. A manual-hydraulic press made in capacities of 25–125 tons is shown doing typical work in Fig. 1.

The **mechanical power press** may be driven by a belt from a motor or line shaft or by a self-contained electric motor. A heavy, rapidly rotating **flywheel** is usually provided so that one working stroke of the press may be performed with a reduction in angular velocity of the wheel up to 10 per cent for continuous operation or more for intermittent. The **ram** may be driven directly from the crankshaft on which the flywheel is mounted, as shown in Fig. 4, or the flywheel may be mounted on a backshaft, driving the crankshaft through gears, Fig. 5, when considerable power is required. Geared presses are referred to as being single-, double-, or triple-geared, depending on the number of **gear reductions.** The **crank** is sometimes replaced or augmented by cams or levers for driving the slide of single-action presses. In multiple-action presses, one slide is driven by crank and the other by toggles or cams.

Number of Rams or Slides

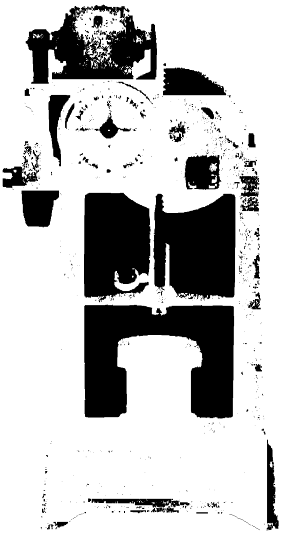
A **single-action press,** Fig. 4, has but one moving plunger or ram. This is the simplest type of press and most commonly used for blanking, trimming, punching, and simple drawing work.

The **double-action presses** have two independently operated slides or rams, as described below under *Cam and Toggle Presses*. They are used for combined operations, such as blanking and drawing parts from flat sheet metal, or for perforating and knockout. The outer slide, receiving its motion from the cam or toggle, operates the blanking die or the blank holder of the double-acting drawing die, while the inner slide, carrying the ram or plunger, is operated by the crank and draws the part to shape. See Fig. 29.



Courtesy Dake Engine Co.

FIG. 1.



Courtesy Lucas Machine Tool Co.

FIG. 2.

FIG. 1. The Dake Manual-Hydraulic Press No. 50H of 50-Ton Capacity.

This is built up of structural steel parts with the bed adjustably mounted on the uprights. A bearing race is being forced from the shaft. A small cast-frame manual press is attached to the left upright for small light jobs. Centers and Vees with a dial test indicator are provided on the front bar for checking the straightness of shafts being straightened in the press.

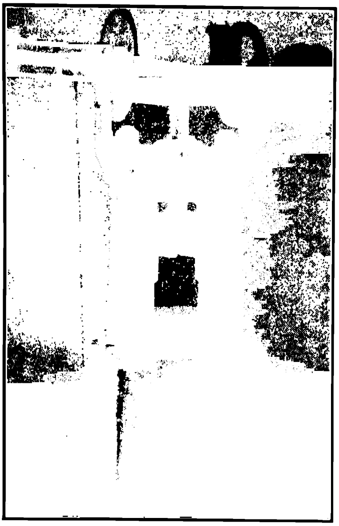
FIG. 2. The Standard 30-Ton Geared Power Forcing Press with Self-Contained Motor Drive, V Plate, and 16-in. V Block.

The **triple-action presses** have three moving slides. They are used in making two drawing operations on a part with one stroke of the press. This saves time and handling and makes unnecessary any annealing operation between draws, as the heat generated by the first draw is still in the part when the second draw is made. The tooling-up cost of such a job is high but is worth while in many cases.

Construction for Applying Power to the Ram

The motor-driven **geared forcing press,** Fig. 2, is made in 15-, 30-, and 50-ton capacities. It is used for a large variety of operations, such as forcing mandrels, bushings, shafts, or pins in or out of holes, bending or straightening, broaching, and burnishing. The working elements consist of a rack ram driven by gearing through a multiple-disk friction clutch which takes power from the continuously driven worm on the pulley shaft. The handwheel is used to raise or lower the ram quickly, and it automatically engages the clutch and applies the power when the ram meets the resistance of the work. The amount of pressure is proportionate to the force exerted. When the handwheel is released or when the resistance on the ram ceases, the action of the press ceases, making it accident proof.

The **percussion press,** Fig. 3, will do work equivalent to that of a 200-lb drop hammer. It is used by jewelry manufacturers for striking up medals, signet rings, etc. Larger presses of this type are used effectively in striking medals and emblems, hot pressing brass and other nonferrous metals, as well as for cold pressing small steel parts, such as cutlery and surgical instruments. They may be used on upper floors as noise or vibrations are not excessive.



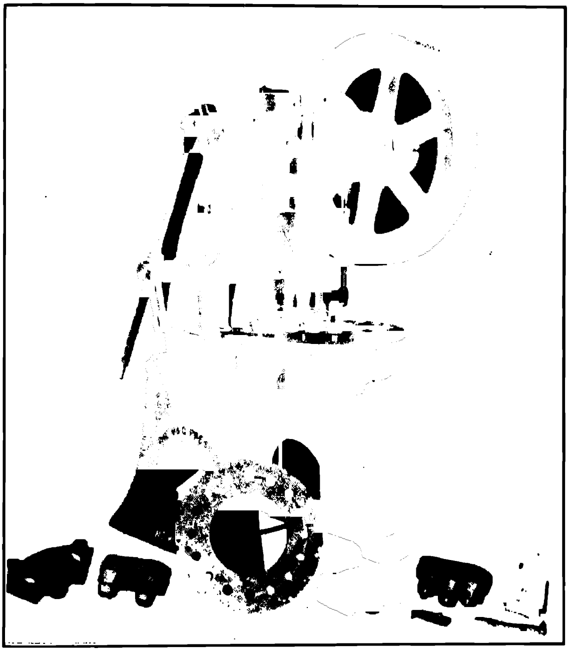
Courtesy Zeh and Hahnemann Co.

FIG. 3. The No. 7 Percussion Screw Power Press Which Exerts a Pressure of 50 Tons through Inertia of Screw Pulley.

Cranks are most often used to actuate the ram of single-action presses. Single cranks are used on presses of small width or high speeds, as shown in Fig. 4, both of light or heavy duty. Two or more cranks, Fig. 5, are employed when the distance between the housings exceeds about 3 ft. The wider presses are usually twin geared on the crankshaft. The double crank (or eccentric) is used on large shears, Fig. 8, and on wide presses using bending, or forming dies, or gangs of punches for the manufacture of light sheet-metal products.

Cam-operated presses usually have a single crank with cams on either side. They are of the double-action type. The crank operates the central ram and the cams operate the outer slide.

Toggle presses, Fig. 6, are of the double-action type and are preferred to those of the cam type for large, heavy, and deep drawing work. They are built in sizes weighing from 35,000 to 1,000,000 lb and are capable of exerting pressure up to 2,000 tons. The plunger is driven through an adjustable-length pitman by single or double cranks on the main shaft, while the outer slide or blank holder is actuated by two rocker shafts connected by links to cranks or cams on the end of the main shaft. These presses are used in making sheet-metal parts, such as automobile fenders, tops, and bodies, chassis frames, steel barrels, and metal caskets involving blanking, drawing, and deep-forming operations.

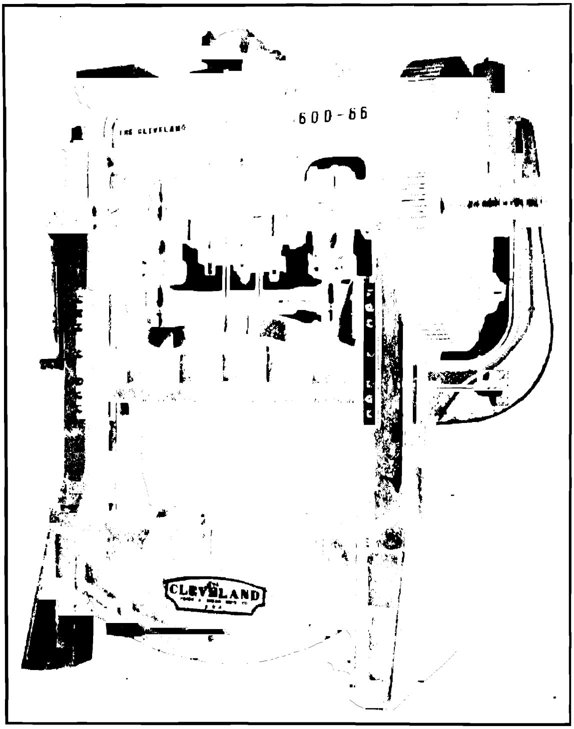


Courtesy V & O Press Co.

FIG. 4. The No. 3 Plain Open-Back, Gap-Frame, Inclinable Press for Belted Drive to Flywheel with Pressure Capacity of 30 Tons.

This press is equipped with automatic dial feed driven from the eccentric on the left end of the crankshaft, with interchangeable dial and two extra sets of interchangeable dies for the manufacture of different sizes of can covers. A positive automatic safety attachment to the clutch insures accurate indexing. A foot pedal is provided for engaging the clutch. The speed of operation is from 50 to 75 strokes per min according to the size and shape of the finished cover.

Knuckle-joint presses, Fig. 7, are built in a number of sizes weighing from 3,000 to 400,000 lb to give pressures of 30–3,000 tons. They are used for heavy embossing and swaging on such work as coins, watch cases, heavy hardware specialties, cold forging, and surface finishing, which require a slow powerful pressure during a small portion of a short stroke. Small presses of this type are built with solid one-piece frames; the larger, as shown, has a built-up frame held together by four steel tie rods encased and shrunk in place in the columns to take the tensile stresses. The knuckle joint is actuated from a crank.



Courtesy Cleveland Punch and Shear Works Co.

FIG. 5. A Double-Crank, Straight-Side, Open-Back, Single-Geared Press.

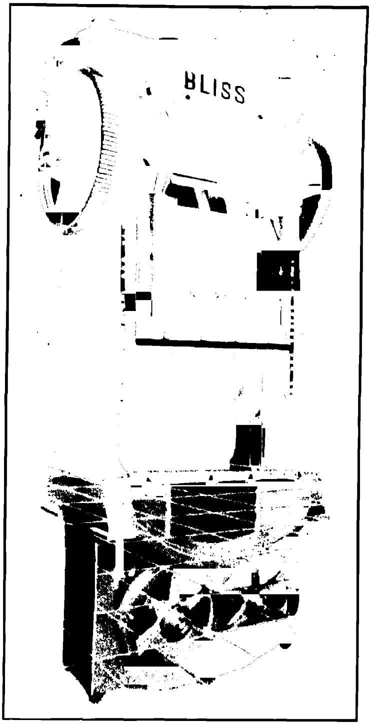
The foot treadle operates the sliding-block clutch, and a hexagonal bar drives the pinions for adjusting the length of the pitman arms to locate the position of the slide. The slide is supported by helical springs.

Hydraulic presses have the ram actuated by means of hydraulic pressure applied to the ram or plunger. These presses are usually for high-force capacity work with the pressure furnished from pumps, accumulators, or intensifiers. Extrusion presses are usually horizontal, whereas forging presses are generally built vertically.

The Use of Presses

Presses are classified variously in accordance with the nature of the work they are designed to do, as follows:

A **punch press** is used extensively as a general utility press for work such as drop forging, cold trimming, cutting sprues or gates from soft castings, and blanking, perforating, bending, and forming sheet metal or flat bars. The slide is driven from an eccentric on the end of the overhung shaft so there can be no bending between the crankpin or eccentric and the main bearing. The throats of these presses vary in depth. Some, called gap presses, have deep throats to accommodate large sheets.



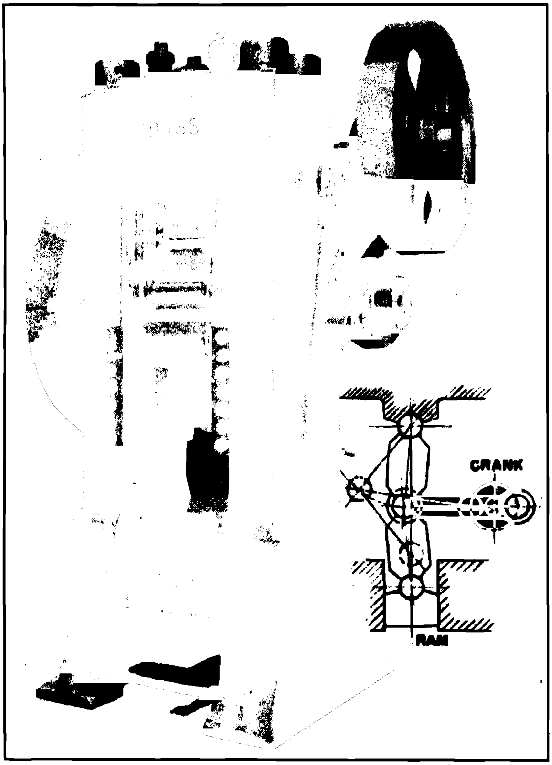
Courtesy E. W. Bliss Co.

FIG. 6. A Bliss Double-Crank Double-Action Toggle Drawing Press Used for Large Work Requiring Double Action in the Drawing, Forming, and Deep Stamping of Irregularly Shaped Articles of Large Area.

Triple-action operations can be performed by the addition of a synchronized third motion in the bed. The outer slide is driven by the toggles from the crank on the gears at the end of the crankshaft to hold down the work while the ram, driven by the double crank from the crankshaft, does the drawing.

A **drawing press** is a press in which drawing dies are used. It is usually of the double-action type so that one sleeve will hold the outer edge of the blank in compression while the second sleeve performs the drawing operation by forcing the plate through an open die. These double-acting presses usually are of the crank and cam type, or of the crank and toggle combination. Single-acting presses often are equipped with a spring-plunger or hydraulic-cushion attachment below the bed to support the holding ring of the die on springs while the drawing is done by the cranks. The holding-ring pressure is adjusted so as to prevent wrinkling of the work.

Trimming presses are of the straight-column or overhanging-frame type with an additional crank or eccentric on one end of the crankshaft, as on the right end of shaft, Fig. 22. The overhung crank may operate sprue cutters or a punch while the dies for trimming the flash are operated by the crank. These presses, built in a wide range of sizes, are especially adapted for trimming drop forgings either hot or cold. The trimming dies may be replaced by punching, blanking, stamping, or bending dies as needed.



Courtesy E. W. Bliss Co.

FIG. 7. The Bliss Knuckle Joint Embossing and Coining Press.

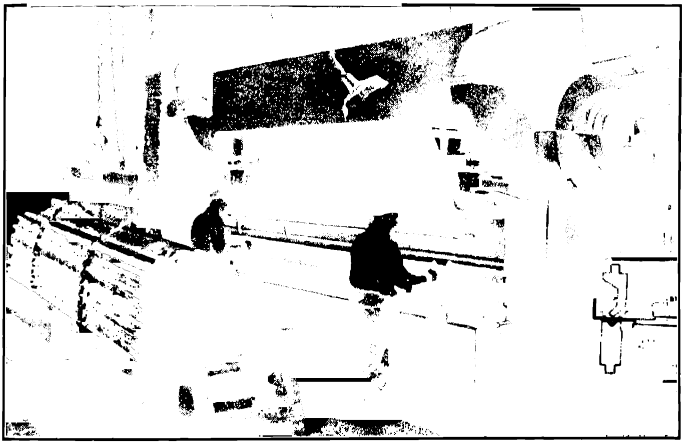
This is a powerful press for embossing, coining, sizing, swaging, and very heavy stamping work. The slow powerful pressure is applied during only the last portion of the stroke. The insert shows how the ram is driven through the toggle by the crank.

A sprue-cutting press is of the gap type similar in shape to the punching press. It is usually equipped with two opposed cutting edges for removing gates and risers from castings, or sprues from forgings before the trimming operation.

Shears are a form of double-crank open-back press of large width designed for the purpose of trimming or cutting large sheets. They are built in various sizes with widths and capacities as required.

Smaller presses for light gage work may be arranged for foot-pedal or hand-lever operation. The sheets being sheared are held by a holddown which is spring cushioned to allow for different thicknesses of plates. The holddown slide is operated by cams on the crankshaft. Cranks operate the shear slide.

These shears resemble **press brakes**, Fig. 8. The latter has forming or punching dies instead of long shear blades. Shears and brakes are used for forming long sheets as required in aircraft and furniture manufacture.



Courtesy Dries and Krump Manufacturing Co.

FIG. 8. A Heavy-Duty Press Brake, Series D, Double Back-Geared and Double-Driven.

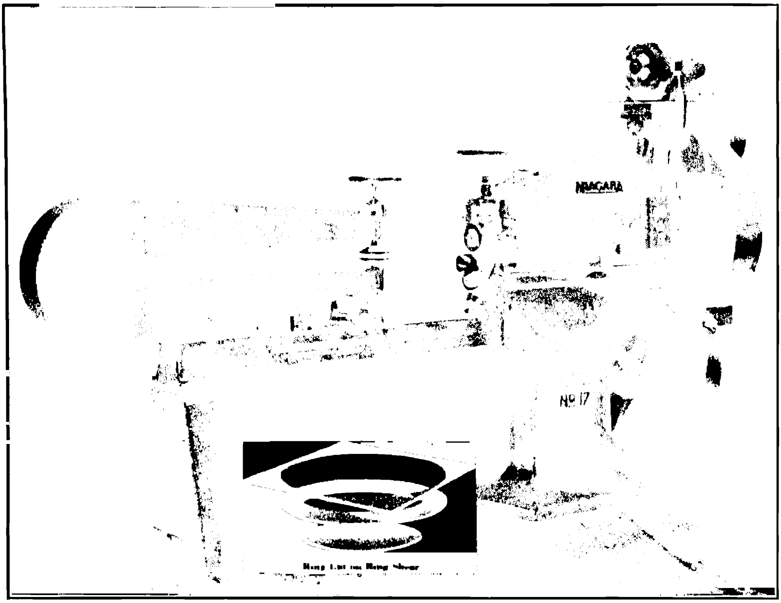
It is provided with dies to finish-form a rectangular tube. The upper slide is driven by two eccentrics. It is of steel welded construction and operated by two men. A wide variety of forming dies and multiple punching attachments makes this brake adapted to form sheets, straighten plates, punch multiple holes, etc.

Shears for **rotary slitting** and **circle cutting,** Fig. 9*A*, may cut straight or curved strips to any width by means of the rotating circular cutters. By clamping the center of the sheets in the circle-cutting attachment, consisting of two flat freely rotating centers, circular disks are cut as the plate is rotated between the cutters.

A shear set up for **flanging** is shown in Fig. 9*B*. Such flanged disks are used in the manufacture of tanks, drums, furnaces, etc. The shear cutters and flange rollers are interchangeable in this machine.

Curving or **band rolling machines,** Fig. 10, are built in a wide variety of sizes and consist of three rollers mounted horizontally or vertically for rolling straight bars or strips previously cut to proper length into hoops or cylindrical shapes.

An **embossing or coining press** is usually of a powerful short-stroke knuckle-joint, or a heavy-duty-crank type. **Embossing** consists of forming thin sheets between dies to produce such work as letters and figures on jar and can tops. **Coining** consists essentially in restriking a slug or forging in a powerful rigid machine to give a permanent cold set to the part to finish it to size or shape. Letters or figures may be formed on the surface. In surface finishing, parts are compressed and sized between dies. Dimensional accuracy as close as 0.0005 in. may be obtained on small parts, but 0.002 in. is more common.



Courtesy Niagara Machine and Tool Co.

FIG. 9A. The Niagara No. 17 Ring and Circle Shear, Which Can Cut Internal as Well as External Circles.

This will cut disks from 10 to 60 in. from a square blank clamped at its center between freely rotating flat centers of the tailstock, which is clamped to the bed for the radius desired. The edge of the plate rests on the power-driven lower cutter. A 2-hp motor is required for sheets of 10-gage mild steel.

A combination horning and wiring press is shown in Fig. 11. A **horning press** is equipped with a horn fitted into the column on which punching, riveting, or bumping side seams on pails, tubes, and other cylindrical articles may be performed.

A **wiring press** usually carries wiring dies and often is provided with a vertically adjustable bed. A horizontally sliding table is sometimes provided which may be manually or mechanically operated to slide the die from under the ram for removing and reloading the work without interference by the ram. Presses of this type are for rolling or curling the edges of pails, coffeepots, cups, etc.

Courtesy Niagara Machine and Tool Co.

Fig. 9*B*. The Niagara No. 407 Circle Shear and Flanger Set Up for Flanging a Previously Cut Disk.

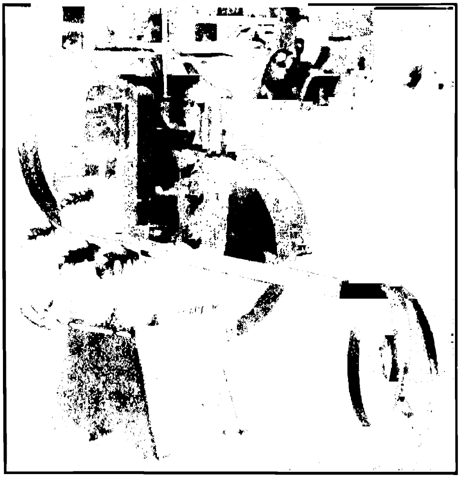
This will roll a perpendicular flange $2\frac{1}{4}$ in. high at 67 fpm of rolls with a $7\frac{1}{2}$-hp motor. The edge of the plate rests on the face of the vertically mounted power-driven roll with the desired overhang for flanging by the adjustable horizontally mounted power-driven roll. Equipped with cutters, the machine functions as a circle shear.

In the **four-post dieing machine**, Fig. 12, the flywheel, crankshaft, and connecting rod, below the punch holder, furnish a pulling stroke to the punch instead of the usual pushing stroke. Standard strokes of 1½ in. are obtainable at a maximum rate of 250 per min. Machines of this type are used for the rapid production of parts of light sheet metal using progressive or multiple dies, Fig. 13.

Gang presses are specially designed for operating long narrow dies requiring considerable power, such as those used for gang-punching rivet holes in sheets for boilers and tanks. They are usually of the gap-frame and double-crank type. Cam-actuated strippers are generally provided so that short durable punches may be employed. The punches are usually placed in different vertical planes so as to act progressively, that is, one punch is starting while another is finishing.

This distributes the load over a greater proportion of the stroke and reduces the maximum cutting force.

An 8-plunger pillar press, known as an **eyelet machine,** is shown in Fig. 14. The plungers are cam actuated on the lighter machines, as shown, but operated by crank on the machines for heavier stamping, deeper drawing, and larger blanking work. The heavier machines are used for making lamp and gas fixture parts, soap and powder boxes and covers, incandescent lamp sockets, oilcan bodies, etc. A typical job on this machine consists of making an oilcan body in nine steps as shown on the left. Knockouts for each stage are operated by cams on a shaft below the dies. Coiled stock is fed to the dies from the roll shown in the foreground.



Courtesy Niagara Machine and Tool Co.

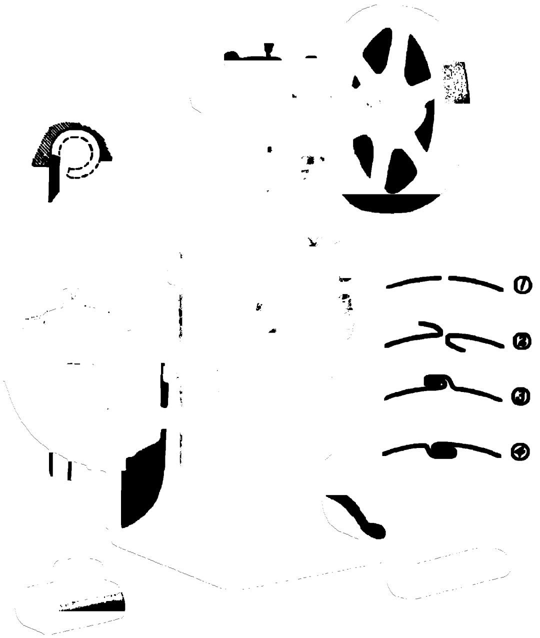
FIG. 10. A No. 3 Forming and Curving Machine for Heavy-Duty Work.

Two 2½- × ¼-in. angle irons are being curved into circles from straight bars previously cut to length. The position of the rear roll determines the ring diameter. The driving roll is serrated to effect a positive feed.

These machines often are hooked up to a thread-rolling machine so that the drawing as finished on the eyelet machine is transferred automatically to the thread-rolling machine placed at the rear.

The **nibbling machine,** Fig. 15, is designed to cut sheet stock to required outlines or to a superimposed templet, as shown in Fig. 16. when the quantity of a part required is not sufficient to justify the making of press blanking tools. These machines are used particularly in small production plants where sheet metal is worked, as in the aircraft industry. This process is fast and gives a better finish than the method of drilling overlapping holes about the scribed lines of the work.

The overhanging arm carries a rapidly reciprocating punch which works above a die supported by the bed plate. The feed is governed by a stop pin of smaller diameter on the end of the punch. The stock is fed against this pin, and a small portion cut away by each stroke of the punch. Standard punches are ¼ in. in diam. The punch reciprocates 650 times per min cutting stock up to $\frac{3}{16}$ in. thick at a rate of 36 in. per min.



Courtesy Niagara Machine and Tool Works.

FIG. 11. A Horning and Wiring Press of the Adjustable Table Type.

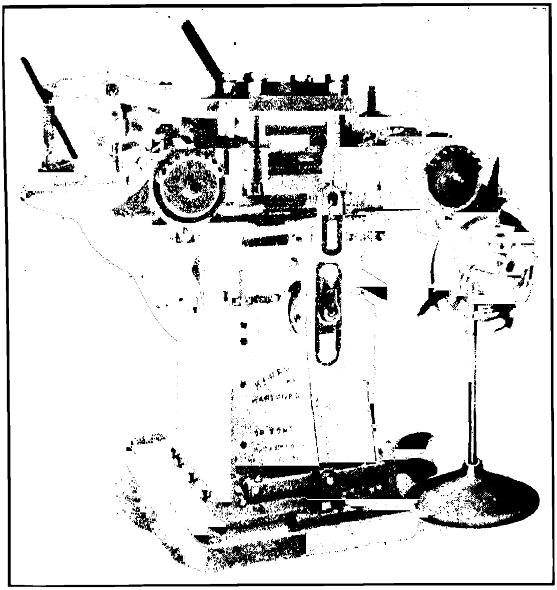
The Niagara No. 14 power press with special duplex slide seamer in place, with swinging adjustable table and dies swung to the left.

Wiring or curling the edge of a cylindrical part is shown in the drawing on the left. The smooth side of the sheared edge slides against the die.

Longitudinal lock seams are made with the horning dies on sheet-metal cylinders up to 18-gage thickness. The line drawing on the right shows the following steps:

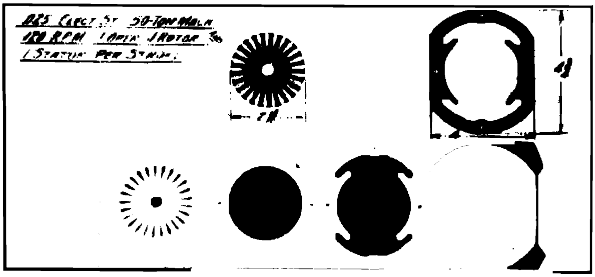
1. Flat blanks are formed into cylindrical shapes on a form roll.
2. Both edges of the seam are folded, using bending dies on both sides of the horn.
3. The folded-in edges are hooked and the seam closed between the horn and rim, being offset for an outside, at 3, or inside, at 4, seam.

The **combination shear, punch, and coper** is designed to work



Courtesy Henry and Wright Manufacturing Co.

FIG. 12. A Belt-Driven 25-Ton Dieing Machine with Stock Reel, Automatic Double-Roll Feed, and Scrap Cutter.

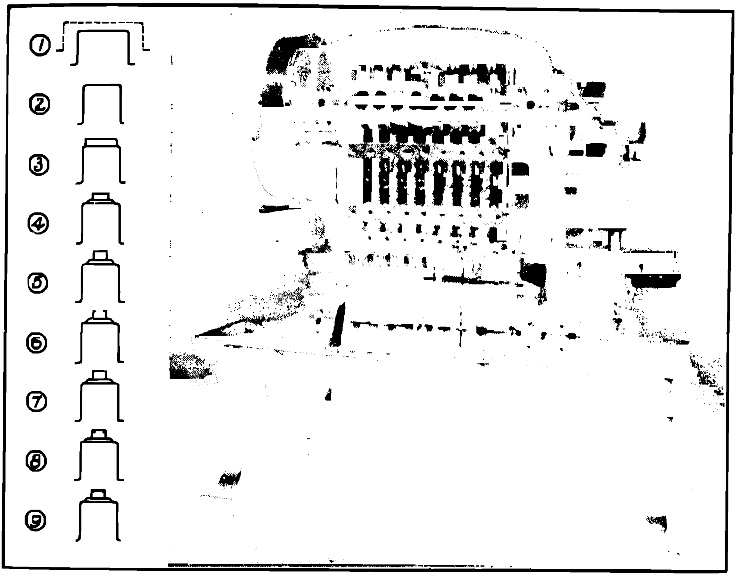


Courtesy Henry and Wright Manufacturing Co.

FIG. 13. Rotor and Stator Laminations Cut Simultaneously from Strip Electric Steel 0.025 in. Thick by Punching and Blanking in a Progressive Die on a 50-Ton Dieing Machine.

The four operations are performed in the progressive die at each stroke.

heavy sheets and structural shapes. It has several working stations. The Ryerson No. 3 has a capacity as follows: punch, $\frac{11}{16}$ in. diam. by $\frac{1}{2}$-in.-thick holes; shear, $\frac{3}{8}$-in.-thick plates; flat bars, $\frac{1}{2}$ in. by 4 in.; angles, 4 in. by 4 in. by $\frac{1}{4}$ in.; tee, 3 in. by 3 in. by $\frac{1}{4}$ in.; and round rods, $1\frac{3}{8}$ in. in diam. The machine is driven by a 2-hp, 1,800-rpm motor.



Courtesy Waterbury-Farrell Foundry and Machine Co.

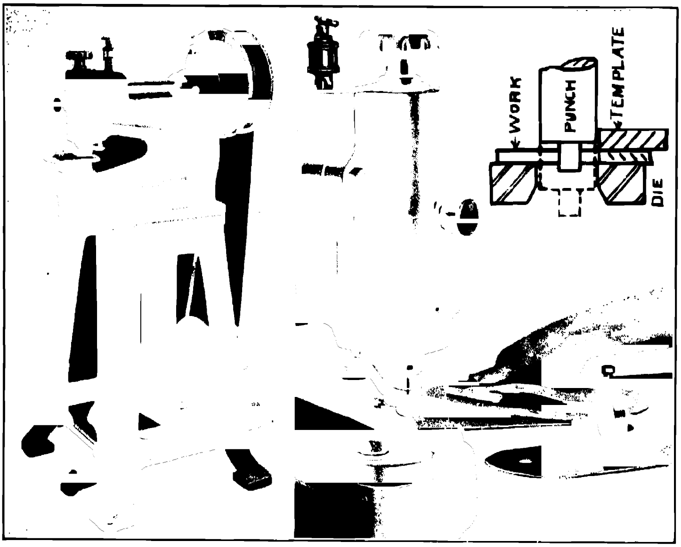
FIG. 14. An 8-Plunger Eyelet Machine Used in the Production of Brass Shells from Thin Coiled Stock.

Spring fingers grip the shell and transfer it from spindle to spindle. Nine operations in the eyelet machine for finishing the body of an oilcan, as shown in the insert, when starting with a blanked and drawn shell shown in dashed lines at the top, are as follows:

1. Redraw, reducing diameter and increasing depth.
2. Again redraw.
3. Reduce end to start breast.
4. Reduce to raise breast.
5. Finish reducing on breast.
6. Punching top hole.
7. Turn down top hole flange.
8. Roll thread.
9. Trim bottom flange.

Clutches for Power Presses

Power presses of the flywheel type are constructed so that the crank, cams, or toggles may be idle until set in motion for each stroke by engaging a continuously rotating flywheel with the driving shaft or gear by means of a clutch. For the safety of the operator, most clutches, when engaged by hand lever or foot treadle, drive the crankshaft for only one complete revolution, after which they are automatically disengaged and the shaft stopped, leaving the ram in its highest position. Some machines, when provided with automatic stock-feeding rolls and scrap cutters on reels, Fig. 12, run continuously after being started until stopped by the operator.



Courtesy Andrew C. Campbell, Inc. *Courtesy Andrew C. Campbell, Inc.*

FIG. 15. FIG. 16.

FIG. 15. The No. 1A Nibbling Machine.

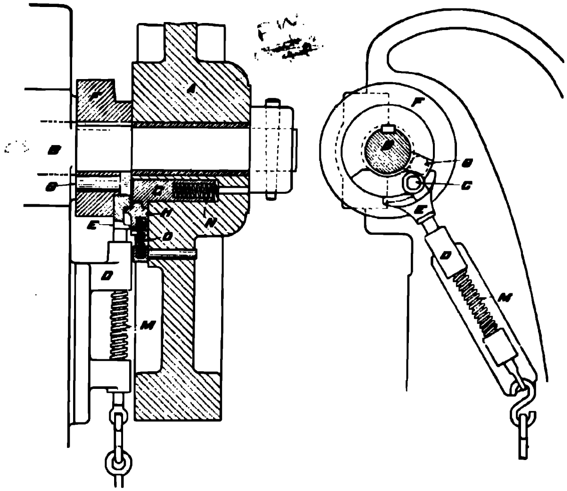
FIG. 16. Cutting on the Nibbling Machine, Using a French Curve as a Templet.

The templet may be used by an unskilled operator not practiced in following a line scribed on the work.

Six types of clutches are used for driving mechanical power presses, as follows: the pin and rolling-key clutches on small presses, the sliding block collar or jaw clutch on larger presses, and the friction clutch of the magnetic, pneumatic, or mechanical type on the largest presses.

A positive clutch of the pin, roller key, or jaw type starts the crankshaft abruptly. It is positively disengaged to leave the slide in its uppermost position at the end of each stroke. The friction clutch starts the press smoothly without shock, and the slide may be stopped at any point of its stroke to fit and adjust dies in heavy presses. To do this with positive clutches, the press must be turned slowly by hand.

A **pin clutch,** Fig. 17, used on most small presses with crankshafts up to 5 in. diam., causes the freely rotating flywheel to drive an adjacent collar keyed or forged on the crankshaft, by a tool-steel sliding pin which has its normal bearing in the hub of the wheel and when released is forced by spring pressure into a recess in the face of the collar.



Courtesy Toledo Machine and Tool Co.

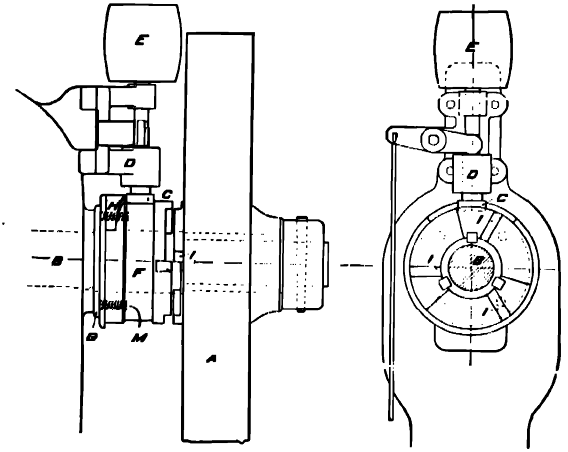
Fig. 17. A Line Drawing of the Automatic Pin Clutch.

Showing a section through the flywheel *A*, crankshaft *B*, clutch pin *C*, and drive collar *F*. The clutch is engaged by pulling downward on the wedge-shaped release *E* which also forces the pin back in the hub after one revolution.

A **rolling-key or rocker-arm clutch** permits an arm to turn a half-round key seated in the shaft. The key engages a half-round keyway in the flywheel, locking it to the shaft. This type of clutch is used on presses with crankshafts up to 10 in. diam. It is gradually being replaced by the pin clutch.

The **sliding jaw clutch,** Fig. 18, is used on slow-speed heavy-duty presses having crankshafts up to 10 in. diam. It consists of a longitudinally sliding stepped collar keyed to the crankshaft with a sliding fit. When released, by raising the weight *E* the jaw is forced along the shaft by coil springs to engage a mating step clutch on the face of the hub of the freely rotating flywheel. This causes the flywheel to turn the sliding jaw and shaft. At the end of the revolution, a cam *H* on the rotating sliding jaw bears against the pin *C* and disengages the clutch.

Friction clutches are used on most of the very large crank and toggle presses. The smooth engagement is particularly desirable where heavy dies are used and the work requires long or deep strokes, or long pressure dwell on the dies as in deep drawing. They have single- or multiple-disk rings attached alternately to the shaft and outer driving casing which are forced together mechanically, pneumatically, or by electromagnets.



Courtesy Toledo Machine and Tool Co.

FIG. 18. A Line Diagram of the Automatic Sliding-Block or Jaw-Type Clutch with Gravity Release, Showing the Flywheel or Clutch Wheel *A*, the Shaft *B*, the Sliding Block or Jaw *F*, and Releasing Cam *H*.

Safety clutches are provided on many presses so that the press is stopped after each stroke even if the operator fails to relieve the starting foot treadle or hand lever. Others are arranged so that electric buttons or levers must be operated simultaneously by both hands of the operator in order to make sure that his hands are not under the press at the time of the descent of the plunger.

Press Accessories

Press accessories for low-cost production consist of such items as safety guards, safety clutches, magazine feeds, stock reels, roll feeds, stock straighteners, scrap cutters, scrap reels, and underneath and overhead knockouts. These devices add greatly to the speed of the operation and the safety of the operator. All actions are synchronized with the stroke of the press.

Safety: In addition to safety clutches, safety guards are frequently installed on presses to make it impossible to trip the press, if the guard cannot first be lowered in front of the dies. The swinging type, Fig. 24, sweeps across the front of the dies forcing hands or arms out of the way as the slide descends. The photoelectric cell is sometimes used on presses to check the engagement of the clutch if hands are within the dies.[2*]

Stock-feeding mechanisms: Many devices are used for automatically feeding strips of flat stock, blanks, or previously formed parts, to the dies of a press. They not only permit an increased rapidity of production, but also assist in protecting the hands of the operator by making it unnecessary for him to put his hands near the dies while the press is operating. The feeding mechanisms generally employed are of the magazine, dial, gravity, slide, grip, single or double roll, and reciprocating types. They may be applied singly or in combination to suit the requirements of each job as illustrated in Figs. 4 and 12 (see *American Machinist*, Nov. 20, 1947, p. 85).

Bar feeds, formerly known as the cut and carry type, are recommended for feeding automatically the work from die to die, Fig. 14, when forming, drawing, or redrawing operations follow blanking, and when great changes in size and shape of the piece make impractical the use of the dial feed.

Roll feeds are the most common feeding devices used for strip stock. The stock is fed between two rolls actuated intermittently by a crank on the press shaft. The feed is stationary and the grip of the rolls released while the dies are functioning so that the work can be lined up properly with the dies. For accurate feed, the use of pilot pins or stop gages on the dies is recommended. These rolls may be used as single rolls feeding the stock to or from the dies or as double rolls.

Grip feeds are more positive and generally used for feeding accurately the heavier gages of material.

Ratchet dial feeds consist essentially of a rotating ring or plate having in it a number of holes or stations, Fig. 4. The ring is indexed by a crank on the press shaft and so timed that the stations come successively under the various punches.

Frequently presses are equipped with **notching devices** so that circular work, such as large armature disks and saws, can be notched in the periphery as the work is indexed at each stroke of the press.

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* Superior numerals refer to entries in the Bibliography at the end of the chapter.

The Bliss **strip feed** is a device applied to presses in the can-making industry for making a press fully automatic for extremely high production. The operator places a pile of strip in a magazine at the front of the press and starts the machine by tripping the clutch. A linkage carrying a suction feed lifts the top strip and places it upon the feed table where the strip is gripped by a push bar which feeds it through the die. The finished blanks fall to the back of the press, and the scrap strip is thrown clear of the press by an ejecting arm as each strip is finished.

Scrap cutters: Scrap cutters are used to cut the continuous strip coming from the dies into short pieces for ease of handling. Frequently the continuous strips are coiled on scrap reels to facilitate handling.

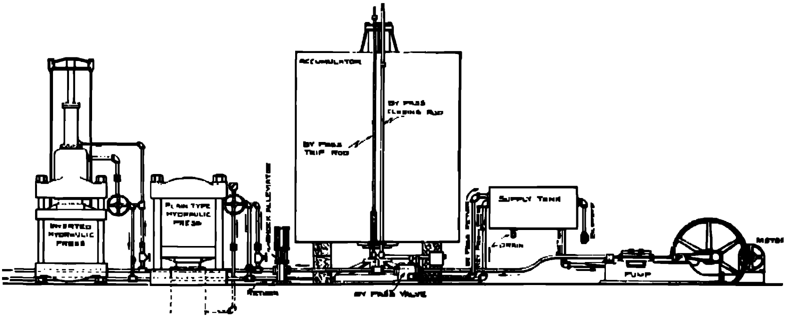
Knockouts for power presses: Many schemes are employed to remove a part from a die after the working stroke. Time is saved and the operator and equipment protected from possible injury when such means are employed. Mechanical knockouts are most generally used. These are operated from the overhanging crankshaft. Others are operated by a rod extending horizontally through the slide so that, as the slide is raised, it engages adjustable stops attached to the frame and holds the rod extending through the upper die, forcing out any sticking parts. Cams located at either side of the crank or below the dies, Fig. 14, also are used to operate bars to knock out the work retained in parts of the die. Gravity or rubber bumpers built into the die or an intermittent air blast greatly assist in the removal of work from dies.

Selection of Presses

E. V. Crane states that the selection of a press involves its size to accommodate the work; its strength or tonnage capacity; the energy available for work or flywheel capacity; the speed of operation or crankpin velocity; and the size of the motor or power required. The **size** of a press may be indicated by the size of the bed within the frame; the distance between the bed and the slide, at the top (open height) and bottom (closed height) of its stroke; the length of the stroke; and the length of the working stroke. A 250-ton press of the knuckle-joint type has a 1½-in. stroke and will work through ⅛ in. The forging press of the same tonnage capacity has a 4-in. stroke and a 1½-in. working stroke; the general utility crank press, 10 in. by 4 in.; the toggle press, 28 in. by 13 in. The weights of the four presses will vary from 12,000 to 145,000 lb. Presses often are rated as to their pressure capacity P in tons, as $P = Cd^2$, in which C is a constant varying from 1.6 to 8.1, depending upon the type of press, form of crankshaft, and number of cranks; and d is the diameter in inches of the main shaft at the bearings ("How Modern Mechanical Presses Operate," *American Machinist,* Nov. 17, 1949, p. 101).

HYDRAULICALLY OPERATED PRESSES

Hydraulic presses have one or more rams driven by manual or power-generated hydraulic pressure. The pressure may be supplied from a self-contained pump as used on the small vertical press for broaching and miscellaneous assembly work, Fig. XIII-4, or from an accumulator or intensifier. An accumulator system is shown in Fig. 19. With sufficient pump and accumulator capacity, any number of presses may be operated conveniently on each of several floors.



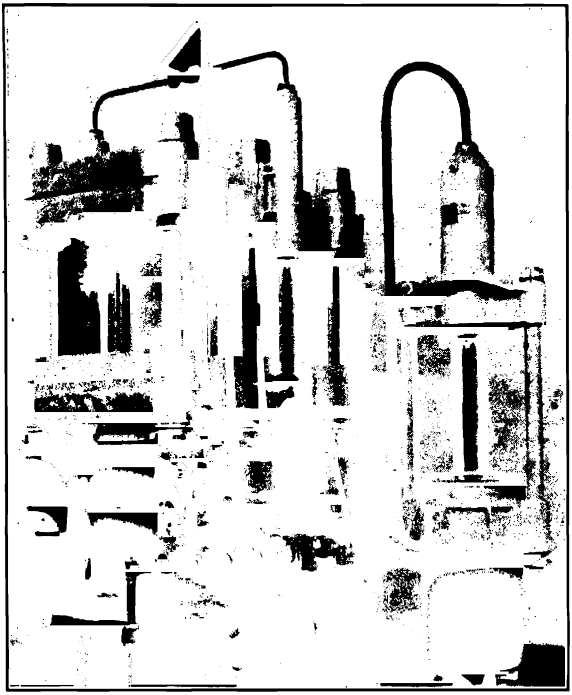
Courtesy Charles F. Elmes Engineering Works.

FIG. 19. A Layout of the Pump, Supply Tank, and Weighted Accumulator System for Driving a Plain and Inverted Hydraulic Press on the Same Floor.

Hydraulic presses also operate with an **intensifier,** as shown in Fig. 20, in which two rams are provided to force the moving platen upward against the stationary head. A 500-lb pressure is maintained in the line by an **accumulator** or pump. The pump running continuously keeps the accumulator at the top of its stroke, maintaining a line pressure of 500 psi.

In operation, the 500-psi pressure water or oil from the accumulator is applied directly to the press rams, and the platen is moved up to the work. During the actual pressing stroke, the 500-psi pressure water is admitted to the low-pressure cylinder of the intensifier, and the 3,000-lb pressure water is then used to do the actual pressing operation. This arrangement effects a saving in the cost of pumping large quantities of high-pressure water. Presses are also built with self-contained electric motor and **hydraulic system.** These units provide features such as instant and automatic control of pressure and speed of the ram and give a cycle well controlled and highly efficient. The press works to pressure limits instead of position limits as do mechanically operated presses. Specific desirable features are as follows:

1. The pressure on the work is applied without shock and as rapidly or as gradually as desired.



Courtesy R. D. Wood and Co.

FIG. 20. A 1,000-Ton Hydraulic Press of the Up-Working Type for Fabricating Metal Airplane Propellers.

It has one $24\frac{1}{2}$-in.-diam. main pressure ram and one $17\frac{1}{4}$-in.-diam. clamping ram located beneath the moving platen. The maximum vertical stroke is 18 in. The intensifier is shown at the right.

2. Pressure and speed of the ram are under positive control and can be varied as desired.

3. The length of stroke can be varied as needed.

4. The pressure applied by the ram during the working portion of the stroke can be set to remain constant and never exceed a set maximum, even though the stock varies in thickness.

5. Rapid traverse of the ram to the work can be made and the speed then reduced as desired for working.

6. Single, double, or triple action is available, any one of which not needed is easily made inoperative.

7. Optimum drawing speeds can be maintained.

8. Inching control is possible for setting up dies and trying out
9. Blank-holder pressure can be varied as the draw progresses.
10. The presses are exceptionally versatile and safe for operators, the dies, and work (*Tool and Die Journal*, July, 1948, p. 46).

Each press may be operated manually or set for an automatic cycle. Manual control through a single lever is used for assembling, bending, forcing, and shaft straightening when strokes of irregular lengths are desirable. The semiautomatic or full-automatic cycle control is best

Courtesy Alliance Machine Co. (Erie Forge Co.)

FIG. 21. A 2,000-Ton Steam-Hydraulic Press Used in Forging a Large Crankshaft.

A 50-ton crane and turning block support the work while the 20-ton manipulator moves and holds the work as it is forged to shape.

for such duplicate operations as exist in practically all classes of die work for blanking, drawing, forming, coining, and embossing.

A **hydraulic flanging press** of the single-frame type has a vertical and a horizontal ram. The work, such as a head of a boiler, is held on the anvil by the vertical ram while the flanging or bending over the edge is done by the horizontal ram operating against the edge of the anvil. Presses of this type are well adapted to miscellaneous jobs, such as flanging and bending plates.

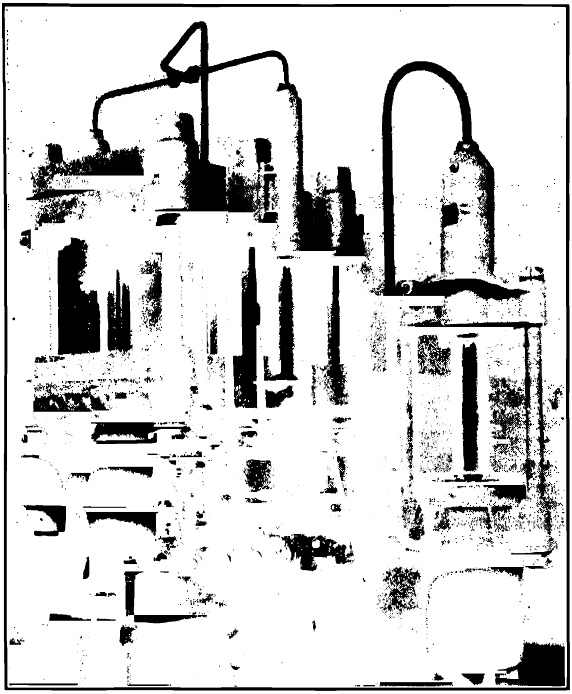
A large **steam-hydraulic press** is shown in Fig. 21.

FORGING HAMMERS AND PRESSES

Forging presses are made as hammers, upsetters, headers, and presses. They may be operated mechanically by gravity, screw, crank, toggle, pneumatically, hydraulically, or by steam.

features such as instant and automatic control of pressure and speed of the ram and give a cycle well controlled and highly efficient. The press works to pressure limits instead of position limits as do mechanically operated presses. Specific desirable features are as follows:

1. The pressure on the work is applied without shock and as rapidly or as gradually as desired.



Courtesy R. D. Wood and Co.

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5. Rapid traverse of the ram to the work can be made and the speed then reduced as desired for working.

6. Single, double, or triple action is available, any one of which not needed is easily made inoperative.

7. Optimum drawing speeds can be maintained.

8. Inching control is possible for setting up dies and trying out stock.
9. Blank-holder pressure can be varied as the draw progresses.
10. The presses are exceptionally versatile and safe for operators, the machine, dies, and work (*Tool and Die Journal*, July, 1948, p. 46).

Each press may be operated manually or set for an automatic cycle Manual control through a single lever is used for assembling, bending, forcing, and shaft straightening when strokes of irregular lengths are desirable. The semiautomatic or full-automatic cycle control is best for such duplicate operations as exist in practically all classes of die work for blanking, drawing, forming, coining, and embossing.

Courtesy Alliance Machine Co. (Erie Forge Co.)

FIG. 21. A 2,000-Ton Steam-Hydraulic Press Used in Forging a Large Crankshaft.

A 50-ton crane and turning block support the work while the 20-ton manipulator moves and holds the work as it is forged to shape

A **hydraulic flanging press** of the single-frame type has a vertical and a horizontal ram. The work, such as a head of a boiler, is held on the anvil by the vertical ram while the flanging or bending over the edge is done by the horizontal ram operating against the edge of the anvil. Presses of this type are well adapted to miscellaneous jobs, such as flanging and bending plates.

A large **steam-hydraulic press** is shown in Fig. 21.

FORGING HAMMERS AND PRESSES

Forging presses are made as hammers, upsetters, headers, and presses. They may be operated mechanically by gravity, screw, crank, toggle, pneumatically, hydraulically, or by steam.

Most hot-forging hammers and presses are provided with accessories consisting of a **furnace** for heating the work before forging and a **press** equipped with a die for trimming the forging flash or cutting off the sprue after forging. Thus, the work is passed by the furnace hand to the forger and thence on to the trimmer. For jobbing work, the hammer and anvil are generally used for forging, as shown in Fig. 21, but when forged parts are to be produced in quantities, dies are substituted, Fig. 22. The dies are made in two halves, one half attached to the ram and the other acting as the anvil. Each **forging die** contains usually from two to five impressions. Each one in turn forms the work to its final shape so as to obtain long life of the die, sound forgings, and a high rate of production at low cost.

Courtesy Erie Foundry Co.

FIG. 22. A 16,000-lb. Steam Drop-Hammer and a No. 24 Tie-Rod Trimming Press.

Used in the production of forgings for companion flanges of 0.25 per cent carbon steel. The finished forging is 15 in. outside diam., $7\frac{1}{2}$ in. bore, and 2 in. thick.

In the **gravity type of press,** the hammer carrying the upper portion of the die is raised and allowed to drop on the work. The board drop-hammer is so arranged that the boards placed vertically with the hammers attached to the lower end may be squeezed between constantly rotating rolls to raise the weight. When the proper height is reached, the rolls are separated, allowing the weight to fall. Drop-hammers of the rope lift type sometimes are used.

These presses, equipped with suitable dies, are appropriate for a wide range of light forging, embossing, and swaging operations on such articles as silver and plated forks and spoons, builders' hardware, stampings for stoves, formed shovels, and small automotive parts.

The **percussion press** shown in Fig. 3 is used for light forging work where vibration is objectionable, as on upper floors.

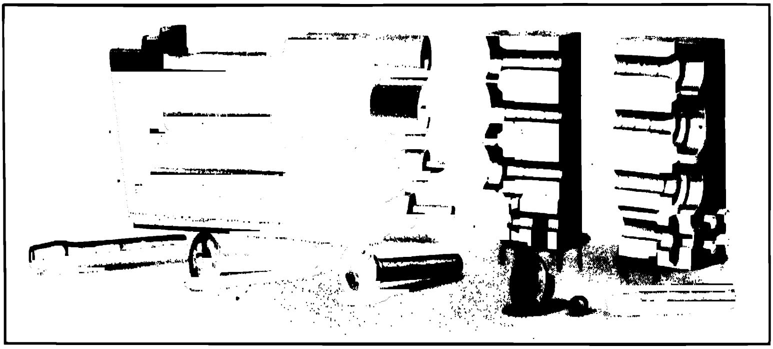
The **crank straight-sided geared press,** Fig. 5, is often used for forging work. It is sometimes equipped with a sprue cutter located on the outside of the frame and driven by an eccentric on the end of the crankshaft, as shown in Fig. 22.

The **steam hammer,** Fig. 22, made in various sizes, is provided with a hammer on the lower end of a ram reciprocated by steam pressure. The operator controls the valve opening so that blows of a wide range of intensity can be dealt as desired. This hammer is of greatest use on forgings of irregular cross section and shape which require blows of different intensities. The Nazel self-contained motor-driven **pneumatic hammer** also gives a powerful squeezing blow similar to that of the steam hammer.

Steam-operated forging hammers are built in the single-frame type similar to a gap-type punching press in smaller sizes for general forging work and in the double-frame type, Fig. 22, up to 20,000 lb. In Fig. 22, stock 10 in. wide by 3 in. thick is sheared or sawed to 10-in. lengths and is being die forged. Allowing for flash, web, tong hold, and for scaling, the gross weight of the stock is 85 lb and the net weight of the finished part is 75 lb. A monorail at the front of the hammer carries a trolley with which the stock, as it is held in tongs, is removed from the furnace and supported during the forging. One corner of the stock is placed on the front edge of the die and a light blow struck to pinch out a thin section to provide a tong hold for holding the part in subsequent operations. The stock, then held by the tong hold, is placed in the impression of a bottom die and given six or eight blows of the hammer. During the forging, a jet of steam or compressed air is used to blow away the scale. Between blows, the forging is lifted out of the bottom impression so that the scale can be blown out. When the material has been forged down so that the dies hit together, it is removed to the side shear of the trimming press where the web is punched out of the center in one stroke. The part is then transferred to the trimming die on the bolster plate where it is pushed through the die, leaving the flash and tong hold above. If gear blanks were to be made, it would be more satisfactory to start with a piece of rough stock 7 in. diam. by 7½ in. long with the grain running lengthwise. This would be upset in the die, producing a radial plastic flow so that all teeth would be of equal strength. By using flat stock, as described above, the original grain structure runs lengthwise, which would give teeth having maximum strength on the two ends and minimum strength on the sides.

The large vertical, **hydraulic press** used for forging, Fig. 21, is provided with a manipulator which replaces many hands in large forging work, and makes it possible to accomplish more in one heat with a great reduction in man power required.

The **crank-operated, high-duty forging machine,** made by the National Machinery Co., is being used extensively for the mass production of forgings. This machine uses expensive multiple-stage dies, Fig. 23, and the work is formed as the heated bar is transferred successively from the top impression to the bottom. A great variety of parts of complicated shape and variable size is upset from bars in these presses.



Courtesy National Machinery Co.

FIG. 23. A Set of Forging Dies for Upsetting the Bevel Gear Blank in Four Operations.

The punches are shown at the left; the die in two halves at the right. The four stages of the gear blank are shown below the dies. As the gear blank is punched off in the fourth stage, a small slug is produced which is the only material wasted. The next blank is made on the end of the bar from which the previous blank was punched.

Headers are frequently used to upset or form parts such as balls and nuts. Work from small bars is formed cold and is fed in the form of coiled wire or bars to the machine. Larger-sized bars cut to convenient handling lengths usually are preheated in an adjacent furnace and fed by hand into the machine. The wire or bar projects through the die to give the proper amount of material needed in the piece. A slug is sheared off and transferred sidewise to the upsetting dies (*Machinery,* May, 1934, p. 565). Knockout pins, working through the center of each die, eject the work from the dies as soon as the punch draws back. The rate of production varies with the size of the machine. Steel nuts for $\frac{3}{8}$-in. thread are upset at the rate of 100 per min.

PUNCHES AND DIES FOR PRESSES

Definition

A **punch,** as the term is applied in pressed metal work, is that part of a press tool which enters into an opening or cavity formed in the die section, as in punching, blanking, drawing, or forming. The punch usually is the upper member, being attached to the press slide or ram; but it may be the lower member, as in the case of press tools of inverted design. When the upper and lower members are similar, as, for example, embossing and coining dies, the upper is commonly referred to as the punch, and the lower as the die, because of their location.

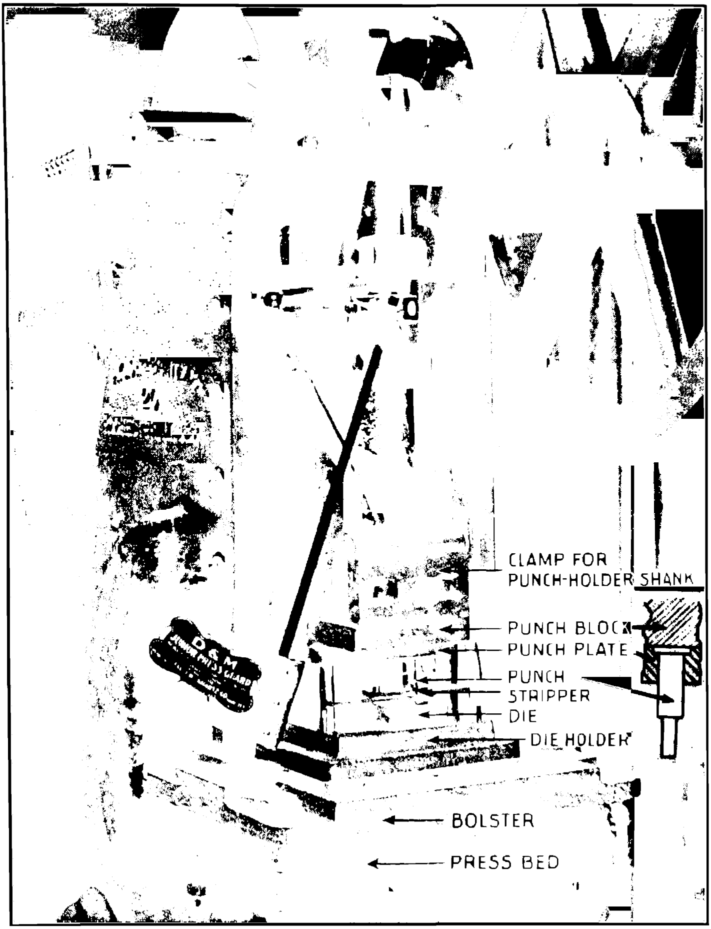
A **die,** as applied to a press tool, is that part which has an opening or cavity to receive the punch. Very commonly the term die is applied to an entire press tool to include both the punch and die as defined above.

Various Parts of a Die

Dies vary a great deal in construction to suit the quantity of production and the types of operations involved. Most dies, as shown in Fig. 24, consist of an upper member comprising a punch, punch plate, and punch holder, and a lower member comprising a stripper plate, die, die holder, and bolster.

The punch or punches are usually held in a steel **punch plate,** doweled and cap screwed to the **punch holder** clamped to the ram. Most standard presses of the smaller sizes are made with an opening or socket in the lower end of the ram to hold the **shank** of the punch holder. In some machines the opening is square, set diagonally, to avoid rotation of the punch. In others the opening is circular, usually with one flat side. Some slides are provided with lugs at the side, so the **flange** of the holders can be attached by cap screws.

The **die** is usually doweled and cap screwed to the die holder in turn clamped to the **bolster** plate which is bolted onto the bed of the press. Figure 11 shows the swinging table supporting the bolster plate on which the die is mounted. Large presses may have the punch and die plates bolted directly to the ram or bed. The face of bolsters may be dovetailed so that dies for many purposes can fit them interchangeably and be held in position by gibs or set screws. The bolster is many times through-drilled and tapped according to a standard layout so



Courtesy Taylor-Schantz Co.

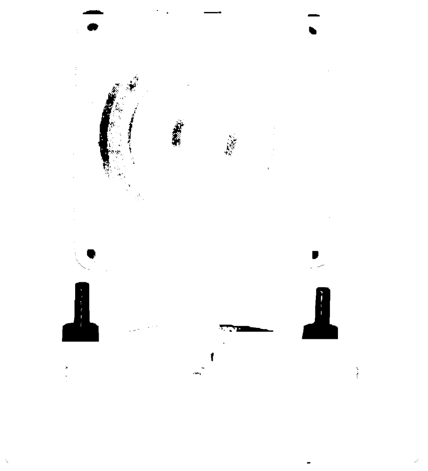
FIG. 24. Die Nomenclature and an Automatic Press Guard.

To protect the hands of the operator from the single-punching die set up on a small inclinable press. As the punch descends, after the clutch has been engaged, the pendulum sweeps across the front of the die and forces arms and hands out of the way.

that all dies, regardless of size and shape, to be used on the press may be attached by cap screws.

The **alignment of the punch with the die** is maintained in operation by the slide in the frame ways and the rigidity of the press frame.

For convenience in mounting the punch and die plates and for insuring their more accurate alignment, **die sets** are now generally used, as shown in Fig. 25. Die sets consist of punch and die holders, Fig. 24. Guide posts fixed in the die holders engage bushings in the punch holder to maintain true alignment.[2] Dies may be provided with two guide posts located on either side of the die at the side or back as shown in Fig. 26. Larger die sets are more often provided with four guide posts.

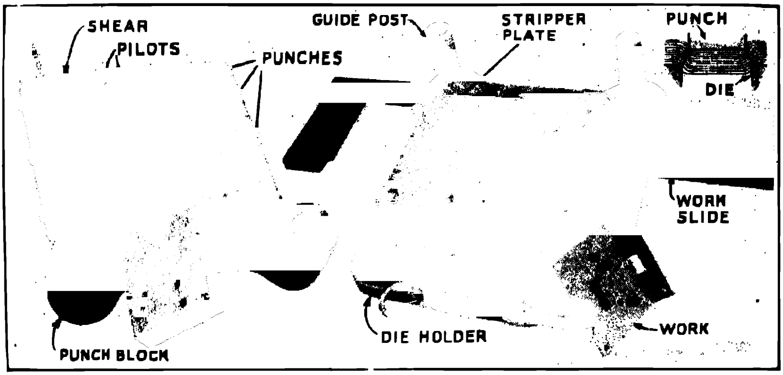


Courtesy Niagara Machine and Tool Works.

FIG. 25. A Four-Guide-Post, Square Die Set for Blanking, Drawing, Embossing, and Punching the Steel Head of a 55-gal Drum.

A number of adjustable self-contained punches and dies such as the Wales shown in Fig. 27*A* are used for the low production of parts as in the aircraft industry. These units, containing the proper sizes of punch and die, are mounted on a T-slotted plate so that the complete built-up die, made up of the plate and die units, is attached to the bolster plate with necessary guides and supports for the work. The work being inserted in the die is punched by means of the ram descending on the punches.

The **subpress**, Fig. 27*B*, was developed by the watch industry to keep the punch and die in true alignment. The upper and lower portions of the die are combined into one self-contained unit which is clamped directly to the bolster. They are adapted for the production of small, delicate, or irregularly shaped work. Subpresses are built either as the arch type, which is symmetrical and rigid and should be used for strip work, or as the overhanging type which makes the die



Courtesy Carpenter Steel Co.

FIG. 26. A Piercing and Cutting Die.

For blanking automobile door main lock plates from 14-gage pickled steel strip on a No. 6 Toledo press at the rate of 1,200 strokes per hr. The strip cutoff shear is shown on the left edge of the punch. The punches are made of 1.10 per cent carbon tool steel hardened at 1,425° F.

The guide for the strip on the triangular punch does not leave the lower die. The strip is fed in from the right beneath the stripper plate perforated in the first stage on the right side of the die, and then moved to the second stage, where two bullet-nosed pilots accurately index the strip for the cut-off and the blanking of the next piece. Seventy-five thousand blanks are produced per grind. The parts shown have been bent in another die.

more accessible and provides better visibility, particularly when blanks are to be positioned in the dies by hand. The usual design embodies a cylindrical cast-iron ram mounted in a babbitt-lined bearing. The plunger is prevented from turning by vertical guiding grooves which slide over vertical keys fitted in the bearing. The grooves are irregularly spaced circumferentially to insure against error in replacement after removal.

Classification of Dies

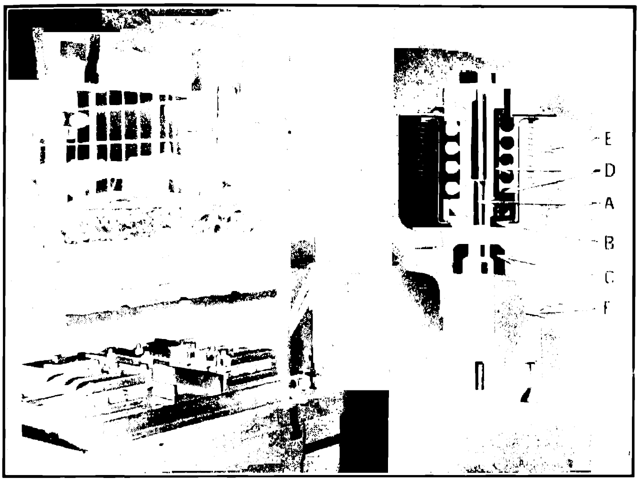
Dies, referring to the punch and die as a unit, may be divided into two general classes as follows:

A. Cutting or shearing dies.
B. Shaping or forming dies.

Cutting dies may be subdivided according to purpose and construction.

Purpose
- **Pierce.**
- **Punch.**
- **Perforate.**
- **Blank.**
- **Shave.**
- **Notch.**
- **Shear.**
- **Trim.**
- **Sprue cutting.**

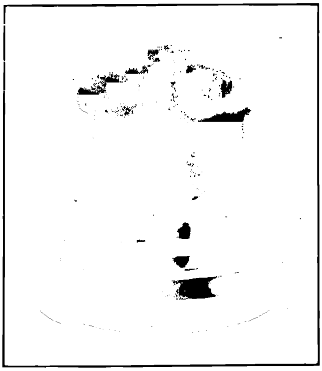
Construction
- **Plain, punching, piercing, or blanking.**
- **Follow or progressive.**
- **Multiple or gang.**
- **Compound (pierce and blank).**
- **Combination (cut and shape, such as blank and draw).**



Courtesy Wales-Strippit Corp.

FIG. 27*A*. A Group of Wales Type "BL" Hole Punch Units Mounted on a T-Slotted Plate, Which Is in Turn Mounted in a Double-Crank Open-Back Press.

These units are used for the production of parts in low quantity. The punch, *A*, punch bushing, *B*, die, *C*, and stripping spring and guide, *D*, are provided in many sizes, all interchangeable in the gap-type holder as shown at the right. They are mounted in the gap-type holder *F* with the other units consisting of the lifter spring *E* and the stripping spring *D*.



Courtesy Waltham Machine Works.

FIG. 27*B*. Arch-Type Cylindrical Subpress.

Shaping dies may change the form of a piece in several different ways.

1. Bending.
2. Curling or wiring, seaming.
3. Drawing, including
    - Combination of blank and draw.
    - Double or triple action.
    - Redrawing.
    - Bulging.
    - Reducing.
4. Compression or squeezing
    - Surface finishing or sizing.
    - Forging, riveting, swaging, upsetting, bulldozing.
    - Embossing, coining, and stamping.
    - Extruding.

Cutting Dies

In cutting operations the metal is pinched between the cutting edges of the punch and die to the point of shearing fracture, as shown by the insert in Fig. 26. Fractures start in the surface of the metal at the cutting edges. Sharp cutting edges of the punch and die localize the pressure and cause fracture more readily than a dull edge.

Purpose of cutting dies: **A punching die** is one in which holes are made. The metal sheared out is the scrap. The cutting edge of the die should be flat, and any **shear** or side slope required should be ground on the end of the punch. A single punching die is illustrated in Fig. 24 and by the insert in Fig. 28. The slug drops through the die onto the floor below. **A blanking die**, Fig. 30, blanks or punches out the material which forms the part The scrap remains above the dies. See Fig. 13.

To prevent the material punched from sticking to the punch as it is withdrawn, a **stripper plate** is fixed over the die, as shown in Fig. 26.

The punch first goes through the stripper plate and then through the work into the die. As it is withdrawn, the work is held against the underside of the stripper plate.

A clean shear of the metal is obtained by having suitable radial **clearance** between the punch and die uniformly around the periphery. Hard metal requires less clearance or difference in radii for a clean cut than soft metal, but, because of its hardness, will work satisfactorily with greater clearance. An old rule is to provide a clearance between the punch and die all around of about $\frac{1}{10}$ of the thickness of soft metal, varying to $\frac{1}{8}$ of the thickness of hard metal, and being as high as $\frac{1}{4}$ of the thickness on some perforating operations where small-diameter punches are used.

The clearance varies for different materials and thicknesses. A rough rule for clearance is to allow 6 per cent of stock thickness up to $\frac{1}{8}$ in. Between $\frac{1}{8}$-in. and $\frac{3}{8}$-in. thickness, clearances of $\frac{1}{64}$–$\frac{1}{32}$ in. are common. The clearance for 0.010-in.-thick stock for brass and soft steel, 5 per cent; medium-rolled steel, 6 per cent; and hard-rolled steel, 7 per cent, is 0.0005, 0.0006, and 0.0007 in. respectively; for 0.100-in. thickness, 0.0055, 0.006, and 0.007 in. respectively; and for 0.200-in. thickness, 0.0105, 0.0120, and 0.0140 in. respectively. For stainless steel, the punch and die should be close fitting with less clearance than for low-carbon steel. About twice as much power is required to punch it.

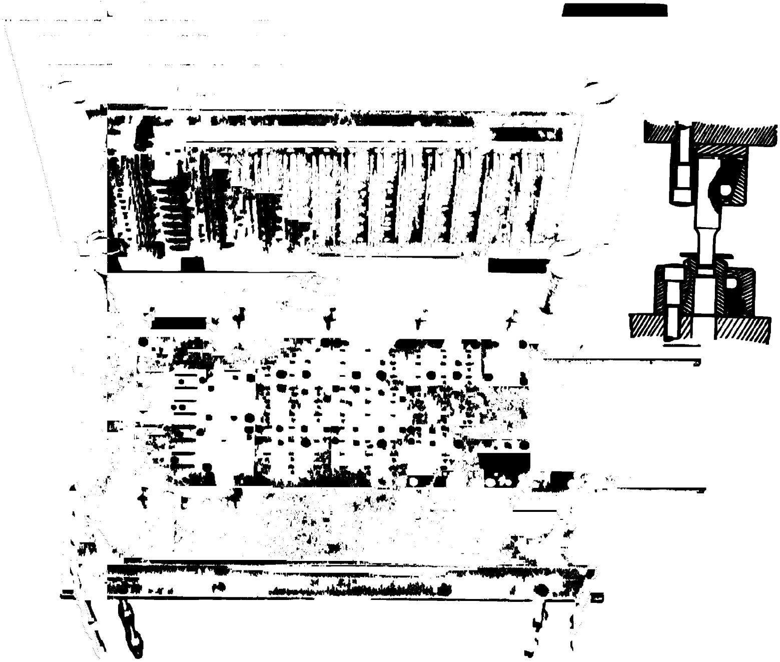
For a die from which only a few thousand pieces are expected, excessive **relief** (5 deg) below the cutting edge should be given, as this permits its being finished quickly. For accurate and permanent dies, 1 or 2 deg is plenty. Some dies for hard metal have no relief for a distance of more than the thickness of the metal, so one slug or blank is always retained. This also permits resharpening without size variation.

Since the blanked part should be flat, the end of the punch is ground flat and any shear angle or side slope is ground on the die. The slope is both ways from the center. When the shape is to be held according to size, the die is made to that size and the punch is made smaller by the amount of clearance.

A **multiple cutting die** is shown in Fig. 26. The upper die, inverted at the left, shows a shearing die and numerous punches set in the steel punch plate, which in turn is doweled and held by countersunk screws to the punch holder. A stripper plate covers the lower die shown on the right. Where a number of punches are used, shear may be applied by stepping the punches. When used with large punches, small ones are shorter by $\frac{1}{3}$–$\frac{1}{4}$ of the stock thickness to prevent breakage.

The punch generally is fitted into the hardened-steel **punch plate,** as shown in the insert of Fig. 24. Whenever one punch supported in this fashion is damaged, the punch plate has to be removed to facilitate exchange or repair. A special punch plate with thrust plate, as shown by the insert in Fig. 28, in general use permits punches of a limited size range having the same shank diameter to be used interchangeably. In case of damage to any one punch, that one punch alone can be removed and replaced in about a minute. The punches of the **multiple-punch die,** Fig. 28, are held in position by this method. Very close center-to-center distances of the punches are permitted.

In designing such **large multiple punching dies,** adequate clearance, rigidity acquired by proper proportions for the kind of materials used, and correct alignment of punches and dies, together with the introduction of interchangeable punches, are important. As a general rule, a punch should be not less in diameter than the thickness of the plate.



Courtesy Allied Products Corp. (Richard Brothers Division).

FIG. 28. A Die of the Four-Guide-Post Type, 34 in. Wide and 52 in. Over-all Size, for Perforating 855 Holes Simultaneously in a Single Hard Cold-Rolled Steel Plate $13\frac{1}{2}$ in. Wide, 36 in. Long and $\frac{1}{8}$ in. Thick, Used in the Manufacture of Automatic Voting Machines.

The punches are held in the punch plates by means of the Richard Brothers interchangeable principle illustrated in the insert, in which a ball in the punch retainer is forced by a compressed coil spring into a groove in the punch shank. The latter groove is inclined slightly less from the vertical than that of the opening containing the ball. The punches are made of carbon vanadium steel No. 2, Table 1, and the dies of high-carbon high-chromium steel No. 10.

In the die illustrated, about 100 of the holes pierced are $\frac{3}{32}$ in. diam., while the plate is $\frac{1}{8}$ in. thick. The pressure to force a $\frac{3}{32}$-in. punch through the $\frac{1}{8}$-in. plate will vary from 1 400 to 1 800 lb., owing to variations in clearance alone. A full-floating positive stripper with ample clearance around each punch will keep it from becoming cramped or allowing the work to become cramped on the punch points. The dies were made with perfectly straight holes for a distance from the top down equal to 1½ the thickness of the metal. This prevents slugs from returning to the top of the dies. The die plate, on which the die sections are attached by dowel pins and countersunk socket-head screws, was machined from a solid 0.40 per cent carbon-steel forging, finished 8 in. thick over-all and 6 in. thick over the bridge. The bridge slot 2 in. deep, planed lengthwise in the bottom, permits the operator to clean slugs from the bolster. The punch block, on which the sectional punch backing plates and holders are doweled and screwed, was forged from the same material and finished to 4 in. in thickness.

Perforating dies are used to punch a large number of small holes in thin sheet metal for producing strainers, sieves, etc. These dies usually are mounted on any standard press fitted with attachments, such as a ratchet or roll-feeding device, to feed the strips to the dies.

Shaving dies may remove from 0.001 to 0.004 in. of metal on the outside of a blank to reduce it to accurate size and shape, or provide a fine finish, such as the fine teeth of a gear blanked from sheet. **Trimming dies** are shearing dies used for trimming the flanges of drawn shells or forgings, Fig. 22, etc.

Follow die punching and blanking, Figs. 13 and 26, is one method of producing blanks with holes in them, such as washers, in one handling in a single-acting press. It is usually faster than the alternative, the compound die, but the product may be somewhat less uniform. In the first step, the hole is punched, pushing the scrap through the die. The work is then moved under the blanking punch where the shape is blanked and pushed through the die. The two operations are done on the same stroke. Frequently a bullet-nosed pilot is provided in the blanking punch, or beside it, to enter holes previously punched to locate the punched hole in the blanking die.

A compound die for punching and blanking is shown in Fig. 25. This actually is a combination die in that the forming operations of drawing and embossing also are performed for which a double-acting press is required. Added illustrations of cutting dies are given with shaping dies in Figs. 33–44 incl.

Shaping Dies

Shaping dies change the form of a piece in different ways. **Bending dies** stress the metal in tension and compression on each side of its neutral axis. Bending is usually not a severe operation, as illustrated by the insert of the horning operation in Fig. 11. Many bending dies incorporate spring pads or spring pins to prevent the metal from creeping one way or another. Frequently bending dies include wedging or rolling actions to get horizontal motion for undertucking. Wedges, frequently in the form of guide posts beveled on one side, serve first as a pilot until the post has engaged the bushing, and then as a wedge to operate horizontally movable members of the dies. **Curling and wiring,** illustrated by the insert sketch in Fig. 11, are largely bending operations.

Drawing dies cause the metal to flow from flat metal or previously drawn shapes into other shapes. The metal remains practically of the same uniform thickness.

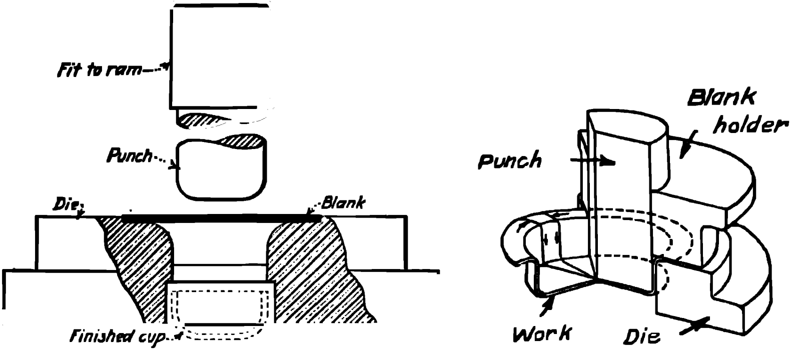


FIG. 29. Drawing Dies without and with Blank Holder.

On the left a disk previously blanked is being pushed through the die with no blank holder. At the right a blank holder holds the disk while the punch forces it through the die.

Cupping, shallow drawing, deep drawing, redrawing, and ironing are forms of drawing operations progressively related. The action of a simple drawing die without and with a blank holder is shown in Fig. 29.

Some low shells, drums, and covers of relatively large diameter and relatively thick metal may be drawn without holding the blank down. Deeper shells require double-acting dies and a brief dwell of a blank holder, for which double-action crank presses may be used with a punch slide and blank-holding slide.

Pressure attachments operated by a coil spring or a rubber spring, as shown at *B*, Fig. 33, may serve to make the die double acting for use on a single-acting press. The machines used may be single-action presses fitted with rubber bumpers for small work, deep-spring-pressure attachments, or pneumatic or hydraulic cushions in the bed of the press. Regular double-action presses, having one crank-actuated slide for drawing and a cam- or toggle-actuated slide for holding the blank, are more desirable, as the holding pressure is adjustably fixed and of long duration.

The force of the punch in drawing a flat blank into a cup, as shown at the right, Fig. 29, causes a radial tensile stress in the metal which produces a resultant compressive stress in the flat portion of the disk being held under the blank holders as the circumference of the blank is continuously reduced to that of the cup. This compressive stress always exceeds the tensile stress and may cause the flange to wrinkle or buckle. Therefore, a considerable pressure on the blank holder is required.

Crane reports that in blanking and drawing light-gage steel in double-action dies, the diameter of the first draw is about 40 per cent that of the disk. In subsequent double-action redraws, using a blank holder, the reduction in per cent may run up to 25, 20, 16, 13, and 10, depending on the relative thickness of the stock and the frequency of annealing between draws. Single-action redrawing without a blank holder requires smaller steps, such as 19, 15, 12, 10, etc., per cent.

Crane reports further that the relation between the diameter D of the blank, and the shell outside diameter d, and shell height h, of thin metal, may be expressed on a basis of equivalent areas as:

$$D^2 = d^2 + 4dh \text{ (for flangeless cup)}$$

and

$$D^2 = d_2^2 + 4d_1h \text{ (for a flanged cup with flange diam. } d_2 \text{ and cup diam. } d_1\text{)}$$

If the bottom mean corner radius r of the shell is relatively large, then

$$D = \sqrt{(d-2r)^2 + 4d(h-r) + 2\pi r(d-0.7r)}$$

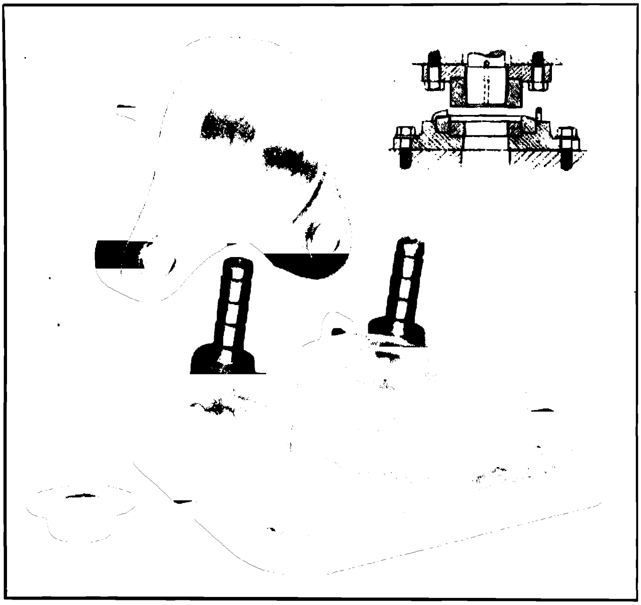
If thick metal of thickness t is used, a ratio of volumes gives

$$D = \sqrt{\begin{aligned}&(d-2r-2t)^2 + 4\ (d-t)(h-r)\\ &\qquad + 2\pi(r+0.4t)\ (d-0.7r-0.3t)\end{aligned}}$$

These results will vary somewhat with the type and hardness of metal used and the fit of the die parts.

A **combination blanking and drawing die** built into a die set is shown in Fig. 30. The **edge of the die** over which the metal is drawn is usually held to a radius of four to six times the metal thickness. A small radius causes excessive thinning of the metal and a high resistance to drawing over the edge. A larger radius may be used where the metal is sufficiently thick with respect to its diameter to preclude wrinkling.

The radial **clearance** between the drawing punch and die usually is more than the metal thickness to permit thickening up and easy flow over the edges. For **ironing** or thinning the wall of a drawn part by forcing it through a die, the clearance may be held to the original thickness of the metal or slightly less. In normal free-drawing operations where the thickening is not objectionable, the clearance may be as high as 50 per cent more than the metal thickness for the first operation draw and 25 per cent more than the metal thickness for the redrawing. The **nose of the drawing punch** also should have a radius of four to six times the metal thickness. The surfaces of the throat of the die, the nose of the punch, the drawing edge, and the blank-holding surfaces should be highly finished in order to avoid picking up material and to prevent breakage of the work when drawing is very severe.

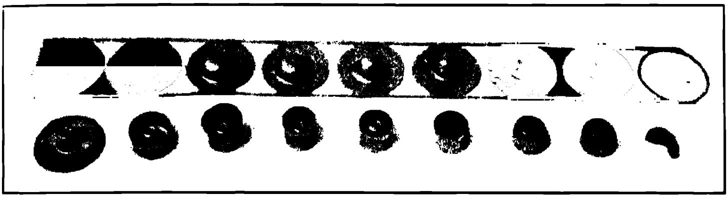


Courtesy Niagara Machine and Tool Works.

FIG. 30. A Two-Guide-Post Die Set with Combination Blanking and Drawing Die for Producing the Small Copper Cup Shown at the Left.

The blank is held between the upper and lower ring, while the punch in the lower die forces the work upward into the recess of the blanking punch. The spring-backed pressure attachment or knockout in the upper die ejects the finished cup from the recess as the ram is raised. The strip is located over the die by means of the two bent stop pins. The insert (by E. V. Crane) shows a combination blanking and drawing die for pushing the work through the lower die, for use on a double-action press.

Stamping operations do not squeeze the metal, but merely bend it up into letters, designs, or corrugations, Fig. 45. **Embossing** compresses the sheet between dies to a flowing pressure to bring up sharp impressions, but does not change original thickness appreciably, Fig. 45.



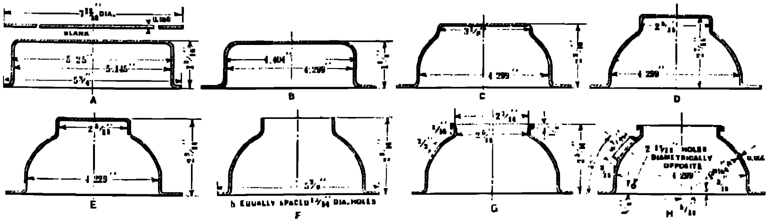
Courtesy V and O Press Co.

FIG. 31. An Illustration of a Series of Blanking and Forming Operations Performed by a Progressive Die in a Press Equipped with Roll Feed.

The lower row shows the successive steps required for finishing the piece in a press equipped with a dial feed.

Bulging produces considerable stretching and may be accomplished by wedge-operated mechanical bulging dies, rubber bulging dies, and by spinning, Fig. 47.

An example of the use of cutting and shaping dies: Examples of work produced from sheet metal by successive die operations are shown in Fig. 31 and in the insert of Fig. 14. To avoid a lengthy discussion relative to the numerous types and the great variety of application of punches and dies, a small sheet-metal part as produced by the Acklin Stamping Co. at Toledo, Ohio, will be described, showing the successive operations on the part and the dies used. A universal-joint boot or cover is made of sheet steel in twelve steps as shown in



Courtesy Machinery Magazine and Acklin Stamping Co.

FIG. 32. Shapes and Dimensions of the Universal Joint Boot after the Performance of Successive Operations on the Dies Shown in Figs. 33–44, Incl.

Fig. 32. The original blanked disk is $7\frac{13}{16}$ in. diam. and 0.050 in. thick. Dimensions of the piece after each operation are shown.

The **first operation** consists of blanking and drawing the part *A*, Fig. 32, in the combination die shown in Fig. 33 set up in a No. 75½ Bliss press. Its action is as follows: after the strip steel is placed over the die and the press tripped, the descending punch *A* blanks the disk as it enters the die ring *C*. At this moment the upper surface of the draw ring *B* is flush with that of *C*. The draw ring *B* is supported on spring buffers located at the lower ends of the pins *D*. The blank is now held firmly between the punch *A* and the draw ring, and as the punch continues to descend, it pushes the draw ring and work with it, drawing the blank over the fixed plug *E*. When the punch ascends, the compressed buffers expand and strip the shell from the plug. *F* is a knockout device in the punch to push the shell free from the punch, allowing it to drop on the die or floor.

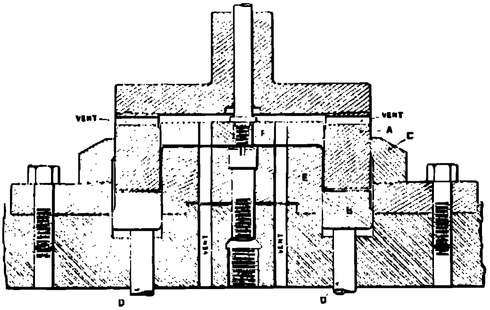


Fig. 33. Combination Blanking and Drawing Die to Produce Part *A*, Fig. 32.

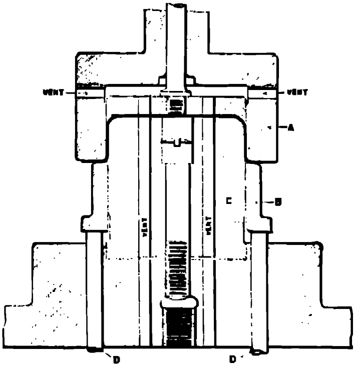


Fig. 34. Redrawing Die to Increase Depth and Decrease Diameter of Body, as Shown at *B*.

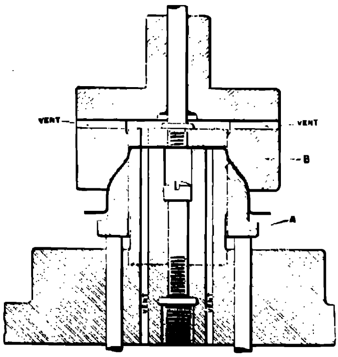


Fig. 35. Second Redrawing Die to Decrease Diameter of Body at the Closed End, as Shown at *C*.

The **second operation** is performed on a No. 74½ Bliss press in the dies shown in Fig. 34. It consists of increasing the depth, decreasing the diameter, and flattening the flange, as shown at *B*, Fig. 32.

The **third operation** changes the form to that shown at *C*, with the second redrawing die shown in Fig. 35 set up on a No. 74½ Bliss press.

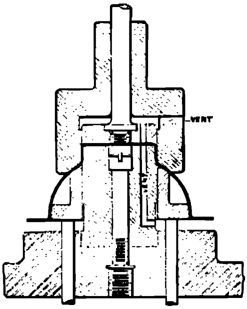


FIG. 36. Third Redrawing Die to Produce Part Shown at *D*.

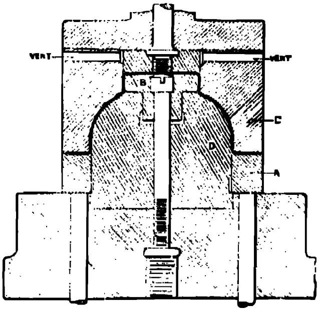


FIG. 37. Final Forming Die to Produce the Part Shown at *E*.

The **fourth operation** draws the shell still further as shown at *D*. The die shown in Fig. 36 was mounted on a No. 74½ Bliss press.

The **fifth operation** is the final redrawing and brings the body of the shell to the shape shown at *E*, Fig. 32. The die in Fig. 37 was set up in the No. 74½ Bliss press.

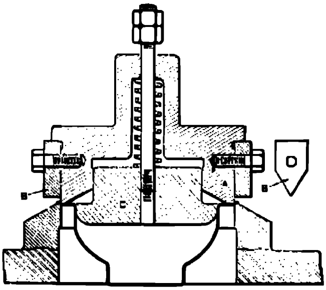


FIG. 38. Die for Trimming Flange to Required Diameter and Cutting the Trim, as Shown at *F*.

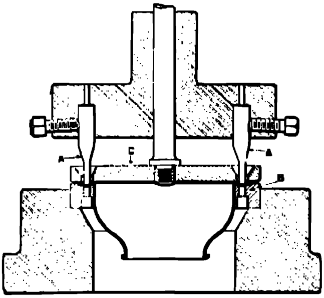


FIG. 39. Piercing Die for Piercing Eight Holes Spaced Equally around the Flange.

The **sixth operation** is performed on a No. 84 Bliss press, using the die shown in Fig. 38. It centers and trims the flange to required diameter, as shown at *F*. The plug *C* centers the work, the punch *A* does the trimming, and the two knives *B* cut the trimmed-off ring so it may drop off. The finished part drops through the die and die-bed into a receptacle.

In the **seventh operation,** eight holes are pierced around the flange of the shell as shown at *F*, Fig. 32, by the piercing die, Fig. 39, as the punches *A* descend on the work and enter corresponding holes in the die ring *B*. The stripper plate *C*, actuated by the knockout on the up stroke of the ram, prevents the work from clinging to the punches. A No. 84 Bliss press was used.

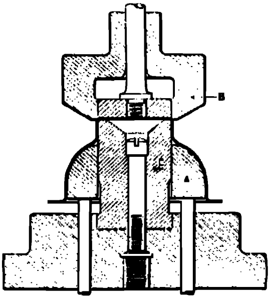


FIG. 40. Punching Die for Punching the Large Hole through the Small End of the Part, as Shown at *F*.

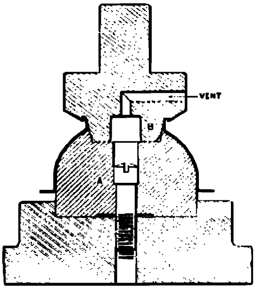


FIG. 41. Tapering and Wiring the Small End, as Shown at *G*.

In the **eighth operation,** the closed end of the shell is punched out by the shearing die, Fig. 40, set up on a No. 73½ Bliss press. In this case the punch (die) *B* forces the work down over the plug (punch) *C* which shears the work from the inside. The ring *A* follows the ram on the up stroke and strips the work from the plug, while the usual pressure attachment is shown in the punch *B* for ejecting the slug.

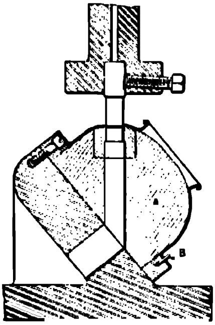


FIG. 42. Punching a Hole through the Body, as Shown at *G*.

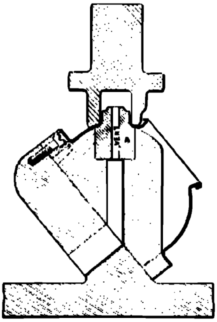


FIG. 43. Die for Flanging the Hole Punched in the Preceding Operation, as Shown at *H*.

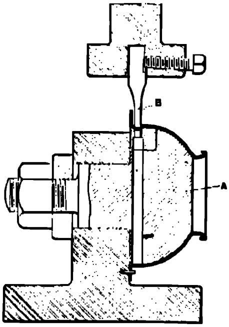


FIG. 44. Die for Punching Two Small Holes in the Body Close to the Flange.

The **ninth operation** spreads or tapers the small end and then wires the edge as shown at *G* by the die shown in Fig. 41 set up on a Bliss No. 84 press.

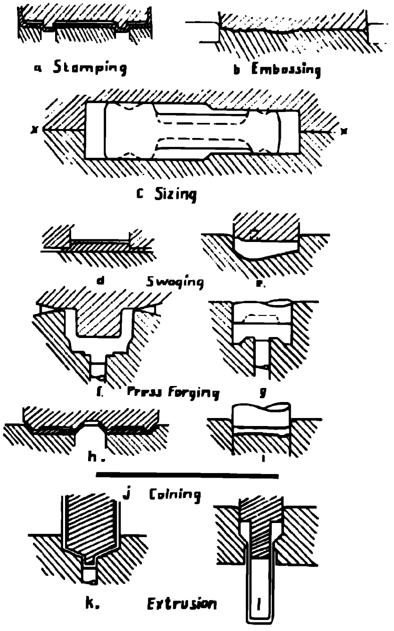
The **tenth operation** cuts the ½-in. hole in the body of the shell as shown at *G*, Fig. 32, by means of the die shown in Fig. 42 set up on a No. 52 Bliss press. The part is slipped over the plug *A* and properly located by inserting the pin *B* through one of the holes pierced in the flange. The slugs drop through the hole in the die.

The **eleventh operation** is flanging the ½-in. hole, as shown at *H*, using the die shown in Fig. 43 set up on the No. 73½ Bliss press.

The **twelfth and final press operation** on the part pierces the two small holes, diametrally opposite, through the body, as shown at *H*. The dies shown in Fig. 44 were mounted on a No. 52 Bliss press.

Compression or Squeezing Dies

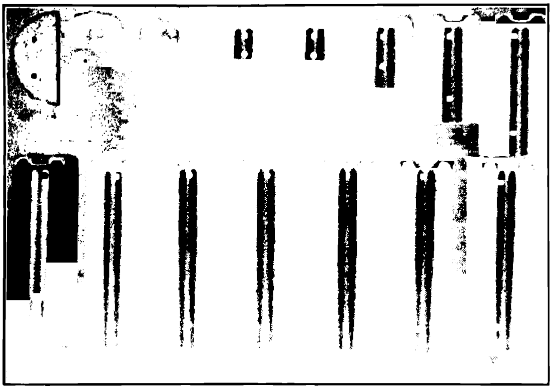
Compression or squeezing operations, shown at *c* to *l*, Fig. 45, represent the severest of all press operations. The metal may be compressed between the punch and die hot or cold. The least severe squeezing operations are the flattening or **sizing** of surfaces of forgings, etc., as shown at *c*. The metal is free to flow at the sides. The rugged knuckle-joint-type press, the very heavy-duty crank press, or the hydraulic press is used for this work. **Swaging,** at *d*, upsetting, and cold forging are severe operations in which a blank or slug is squeezed into an appreciably different shape in a closed die. The blank or slug is first cut to suitable shape and size and then squeezed to the desired size and form, after which it is trimmed.



Courtesy E. W. Bliss Co.

FIG. 45. Typical Compression or Squeezing Operations Illustrating Differences in the Freedom of the Material or the Restriction of Metal Flow.

In **press forging,** at *f* and *g*, the metal is squeezed to shape in fast tie-rod frame machines with eccentric-type shafts, or other heavy-duty types. Press forgings usually have a good finish and are close to size. Various metals are forged hot or cold by a single stroke of the press. In hot forging the pressure is reduced to about one-third of that of cold forging. **Coining** represents a severe squeezing operation in which the metal is confined in closed dies and forced to flow slightly to fill the cavities of the die. Knuckle-joint presses are usually selected for such work on a basis of two to three times the static test load. **Extrusion,** at *k* and *l*, is one of the severest squeezing operations. A slug is confined and compressed and forced to flow rapidly through an orifice. In extruding tooth-paste tubes, a blank of pure aluminum is placed in the recess of the die. The punch, being less in diameter than the die, forces the metal up around the punch as it enters the die. The bottom of the die and the end of the punch are shaped to give the desired form to the tube head. **Ironing** is an operation to reduce the thickness of drawn shell walls by pushing them through tight dies.



Courtesy E. W. Bliss Co.

FIG. 46. The Operations Required in the Production of Brass Cartridge Cases as Performed in a Knuckle-Joint Press.

A group of operations in the manufacture of brass cartridge cases is shown in Fig. 46. The process starts with a blank, after which it is cupped. Additional operations are then carried out in sequence as shown. The case is ironed in steps 4, 6, 7, 8, 9, and 10, and the end is shaped by coining in steps 3, 5, and 11. The center indenting and flange upsetting, as well as the wall ironing, are essentially cold forging.

Materials for Punches and Dies

The material best suited for making up punches and dies depends upon the nature of the work to be done and the quantity to be produced. Abrasion, strength, and high temperatures are the principal factors involved. A great variety of steels are available for hot- and cold-working dies. For a complete list with specific heat treatments, see *Metals Handbook*. The types of steels used include carbon steels, semihigh speed steels, high speed steels, and numerous alloy steels, as listed in Table 1.

Chromium-plating steel dies to a thickness of 0.004–0.012 in. for drawing operations is successfully employed. Wearing surfaces in dies are sometimes surfaced with or built up with inserts of hard materials, such as Stellite and sintered carbide.

Dies with the working parts made of **sintered carbide** have become generally used during the last few years. They can be operated at speeds considerably higher than those for steel dies, up to 1,800 strokes per minute. For blanking, piercing, and notching sheet metal, production of 20–100 or more times that obtained with steel punches and dies has been obtained. While the initial cost is higher, these dies give lower cost per piece produced, longer life of dies, and longer life per grind. Also, there is less scrap and greater freedom from burrs as the dies' edges remain sharp. Carboloy 55A for light work and 55B for general blanking work are used, as these combine high resistance to wear and impact (see *American Machinist*, Feb. 10, 1949, p. 85). The Lincoln Park Industries manufacture many dies of this type which are giving superior performance. See Fig. 13. Sometimes antifriction die sets are used which have ball- or roller-bearing bushings and hardened steel posts assembled with a slight preload.

Kirksite metal dies as developed for the aircraft industry offer a fast die and stamping service to the automobile, truck, bus, and trailer coach manufacturers. These are metal dies of low hardness and low melting point which can be produced in relatively short time for large drawings to be manufactured in small quantities, or for making an inexpensive die in a short time for checking the design before permanent dies are constructed for mass production. Kirksite dies may be **chromium** plated to increase their life so that several thousand parts may be produced. The dies are generally used in slow-production machines or in the stretcher press. In preparing the die, a master male model is prepared from wood, from which a female plaster model is made. The pattern for the female Kirksite die is then made in an open-face sand mold from the plaster mold. The Kirksite metal, heated to about 840° F, is poured into the cavity to form the female die section. This can be used as a mold surface for the lead punch by heating the die to about 250° F and sprinkling with carbon black after which the molten lead is poured into the cavity (*Iron Age*, April 15, 1948, p. 78).

Die sinking for drawing, stamping, forging, die casting, and molding

TABLE I. COMPOSITION OF STEELS AND CAST IRON USED IN MAKING PUNCHES AND DIES, NOS. 1–12, INCL., STEELS NOS. 13–18 USED FOR MAKING DIE CASTING DIES*

No.	Class	Chemical Analysis, Elements in Per Cent										Properties and Use
		C	Si	Mn	P	S	Cr	Va	W	Ni	Fe	
1	Plain carbon tool steel	0.85 1.20	0.30 Max.	0.30 Max.	0.30 Max.	0.03 Max.					Bal.	General light-purpose tool steel. Shear blades; punches; cold-drawing, heading, and trimming dies.
2	Chromium-vanadium tool steel	1.05 1.15	0.25 Max.	0.30 Max.	0.02 Max.	0.02 Max.	0.50†	0.20			Bal.	Hard and shock resisting. For light-duty tools, taps, punches.
3	Oil-hardening steel (Mn Cr–W)	0.85 0.95	0.25 Max.	1.20 1.40	0.02 Max.	0.02 Max.	0.40 0.60	0.15 0.25‡	0.40 0.60		Bal.	Nondeforming. For broaches, blanking, forming, trimming, and punching dies, taps, gages.
4	Oil-hardening steel (Mn)	0.85 0.95	0.20 0.40	0.90 1.15	0.02 Max.	0.02 Max.	0.50 0.90	0.15 0.25‡			Bal.	Nondeforming. For broaches, blanking, forming, trimming, and punching dies.
5	Semihigh speed or finishing steel (oil hardening)	1.25 1.40	0.20 0.40	0.15 0.30			0.35 0.75	0.10 0.25	1.50 2.50		Bal.	Good hardness penetration. Used as finishing tools and wear-resisting punches and dies.
6	Tungsten hot-work die steel	0.35 0.40	0.25 0.35	0.25 0.35			3.00 3.50	0.20 0.40	8.00 10.00		Bal.	High toughness and hardness when hot. Hot drawing, hot heading, bulldozer dies.
7	Silicon-manganese steel	0.50 0.65	1.50 2.50	0.75 1.00							Bal.	Good wearing qualities for chisels, punches, and shear blades.
8	Nickel-chromium steel	0.50 0.70	0.30	0.60	0.04	0.04	1.00			1.50	Bal.	Sometimes 0.30 Mo and 0.18 Va are added. High-duty forging dies.
9	Cr-W low-alloy punch and chisel steel	0.40 0.55					0.50 1.50	0.20 0.40‡	1.50 2.00		Bal.	High toughness and hardness. For light-duty, hot-working tools.
10	High-carbon, high-chromium steel	1.50 2.50	0.50	0.25 0.50	0.25		10.0 14.0		§		Bal.	Very hard and wear-resisting, nonwarping and nonshrinking. Dies for maximum production.
11	Nickel-chromium cast iron	3.25	1.25	0.45	0.18 Max.	0.10 Max.	0.70			2.00	Bal.	Large forming and drawing dies. Heat treated.
12	Nickel-chromium cast iron	3.00	1.45	0.90			0.90			3.00	Bal.	Very large fender and body dies, not heat treated. Also used for high-grade cylinder blocks, pistons, and rings.
13	Low-chromium steel	0.45	0.30	0.75			0.80				Bal.	A low-alloy steel for die-casting dies for lead, tin, and zinc alloys.
14	Chromium-vanadium steel	0.45	0.25	0.75			2.10	0.25			Bal.	A low-alloy steel for die-casting dies for lead, tin, zinc, and short runs for aluminum.
15	Chromium-vanadium steel	0.40	0.95	0.30			5.25	0.50			Mo 0.85	For die-casting dies for high production of aluminum, lead, tin, and zinc alloys.
16	Chromium-tungsten hot-work steel	0.38	0.95	0.25			5.25		4.50		Co 0.50‖	High-wear resistance and very good for die-casting dies for aluminum, lead, tin, and zinc. Fair results are obtained for brass and bronze dies.
17	Tungsten hot-work die steels	0.28	0.25	0.30			4.00	0.50	15.00		Bal.	Used for die-casting dies for brass and bronze.
18	Tungsten hot-work die steels	0.35	0.30	0.30			1.50		12.00		Bal.	Used for die-casting dies for brass and bronze.

* For high-speed steels, see Table V-1.

† Either chromium or vanadium.

‡ With or without the vanadium. Is deep hardening and highly resistant to abrasion.

§ With or without 0.70 Va, and with or without 0.70 Mo.

‖ With or without the Co.

dies is done by hobbing (hubbing) or machining. In hobbing, the die cavity is made by forcing a punch (hub) of desired shape into the hot or cold die metal. Machining usually involves duplicating machines operated manually, hydraulically, electrically, or pneumatically. The cutter, usually of the end mill type, machines from the solid die block while a pilot or pointer traverses the contour of the surface of the template or model; see Fig. VIII-21. A wide variety of tools is required for finishing the surfaces of the dies. These consist of chisels, hand files, scrapers, and solid and coated abrasives. Electric- or air-powered portable tools drive these tools such as steel burrs, rotary files, small end mills, small mounted and replaceable grinding wheels, coated abrasive wheels, sanding drums, polishing and wire brush wheels, all made up in a wide variety of sizes and shapes for the various classes of work. These are used to finish the die cavities as shown in Fig. XV-11, in order to provide a smoothness of surface which will permit long wear of the die and at the same time give the proper surface finish to the work ("Die Sinking for Drop Forging," John Mueller, *Steel Processing*, June, 1949, p. 301).

Materials Worked in Dies

There always enters into the use of dies a certain amount of setting, trying, and relieving to get smooth operation and a satisfactory product. The properties of the material being worked and the lubricant used greatly influence the action of the die.

Metals of practically all types, including aluminum, brass, bronze, copper, magnesium, steel, and zinc, are cold rolled into sheets or strips to be punched, bent, stamped, drawn, and formed into parts. Metal having a low elastic limit compared with its ultimate strength is desirable for deep drawing. This ductility is present in the steels of lower carbon content. The most-used steel for deep-drawing and extra-deep-drawing operations is a low-carbon open-hearth steel with 0.05–0.08 per cent carbon and 0.25–0.50 per cent manganese. SAE 1010 steel is used for light drawing and stamping work.

This low-carbon steel is manufactured in two varieties, strip and sheet. **Strip** usually is produced by the continuous rolling process in various gages up to 0.250 in. thick and up to 24 in. wide on two-high mills. **Sheets** are wider and rolled in four-high mills. Both sheet and strip are reduced hot or cold.

In **cold reducing,** the metal is hot rolled to within 35–50 per cent of final gage. It is then pickled and cold reduced to within ½–1 per cent of final gage, normalized, box annealed, and then given final cold-rolling skin passes to produce correct size, proper stiffness, and good surface, and to prevent stretcher strains in drawing. Stretcher strains are lines of depressions or elevations which destroy the smoothness of the surface. Costly polishing or spinning operations are necessary to remove them. The highly finished surface produced by cold rolling will take plating with very little polishing and buffing.

Sheet and strip for less exact work are made by the **hot-reducing** process. The material is reduced to within ½–1 per cent of final gage on the hot mill. After normalizing and box annealing, it is given cold-rolling passes to "temper." This temper prevents stretcher strains and gives the necessary stiffness for the desired type of drawing operation.

Steels of this type are manufactured in several **tempers** which indicate the ductility and degree of hardness or resistance to bend, as dead soft, skin rolled or planished, ¼ hard, ½ hard, and hard, depending upon the amount of cold reduction through the rolls. The hardness Rockwell "B" of dead soft is under 55 and of hard over 80. See ASM *Metals Handbook*. For high-finish auto-body work and most deep- and extra-deep-drawing jobs, the material is purchased on a basis of satisfactory performance, the actual forming dies being considered the best testing machine. The practice of producing the satisfactory stock is left to the mill.

Both sheets and strip are rolled to decimal thickness. The thickness of sheets is sometimes indicated in U. S. gage sizes, and strip in Birmingham gage sizes, but both always should be indicated in decimals of an inch. A No. 19 U. S. gage sheet, 0.0437 in. thick, of good deep-drawing steel, would have a Rockwell hardness of B-45 to 52, a tensile strength of about 45,000–52,000 psi, a yield point of 28,000–34,000 psi, and an elongation in 4 in. of 33 per cent. These values are increased as the hardness is increased; the harder the steel, the greater will be the spring back in the die. Also, smaller clearance between the drawing punch and die is required. Die trouble caused by hard sheets or strips or by work hardening between operations may be overcome by annealing or normalizing. Normalized steel appears stiffer, but has excellent drawing properties.

Cold-rolled steel should be purchased on a basis of weight required, width in inches, length in feet, and thickness expressed in decimals of an inch. Tolerances in width and thickness should be indicated and the type of edge desired or permitted. The nature of the surface desired, as bright, extra bright, nickel plate, blued, tinned or leaded, hot or electrogalvanized, or coppered, should be specified. It should be specified further whether this material is wanted in continuous coils or in flat strips in 6- or 8-ft lengths.

Tensile strength, yield point, elongation, Rockwell hardness, and the depth of cup as determined on the Tinius Olsen ductility tester are the usual factors which evaluate **drawing quality** of sheet and strip. A fine uniform grain, as shown by photomicrograph, also is desirable.

The Olsen ductility tester is used as a means of checking the workability or **ductility** of the metal sheets. A specimen of the sheet or strip approximately 3½ in. sq is clamped between two dies. A hemispherically ended punch or steel ball forces the sheet through a die until fracture occurs. The thickness of the specimen is measured, the depth of draw at the time fracture occurs, and the load for any depth of draw and at destruction are recorded. The depth of impression required to cause fracture is read directly from the micrometer scale and represents the ductility value of the metal. The test also indicates the nature of the fracture, whether it runs around the dome or whether an undesirable previous fracture in one certain direction is noticeable. It also indicates whether a smooth dome may be obtained. Typical depths of cup values at the point of fracture for a No. 19 U. S. gage (0.0437 in.) soft sheet 3½ in. sq, as determined by the Olsen ductility tester, are as follows:

Deep-drawing steel	10.5 mm or 0.413 in.
Extra-deep-drawing steel	11.0 mm or 0.433 in.
Folding and tinned sheet steel	10.1 mm or 0.397 in.
Aluminum	10.2 mm or 0.402 in.
Brass stamping sheet	14.3 mm or 0.563 in.
Copper	12.0 mm or 0.472 in.
Zinc sheet	8.2 mm or 0.323 in.

These values increase along a smooth curve for greater values of thickness and decrease for lower values of thickness.

Stainless steel can be formed or drawn to a much greater extent than ordinary steels, although normal cutting and forming operations are more difficult and costly on stainless steel. The dies and presses should be more rugged and powerful. When stainless steel is substituted for ordinary steel in the same dies, slower operating speeds must be used. Clearance for stainless steel between the punch and die should be about one and one-half to two times that allowed for ordinary open-hearth steel or brass. The allowance for spring back should be two or three times that ordinarily used.

Stainless steel strip in the form of 14 per cent chromium, 17 per cent chromium, or 18 per cent chromium 8 per cent nickel, in the soft temper, permits deep drawing, bending, and forming without expensive annealing and pickling operations. The finish is such that many parts can be buffed without any polishing operations, or in some cases tumbled to give a beautiful permanent luster.

Aluminum 4S cold-rolled sheet is furnished in various tempers as soft (annealed) (O), ¼, ½, ¾, and full hard. These vary in tensile strength from 26,000 for the soft to 40,000 psi for the full hard. In forming alloys of **aluminum**, the chief requirement seems to be that the tools will permit a suitable radius for bending and drawing. The radius varies with both the grade of alloy and thickness of the sheet. Rounding sharp edges and highly polishing the surface of the dies are essential.

Magnesium metal, known as Dowmetal, having a tensile strength of 33,000–40,000 psi, a yield point of 15,000–25,000 psi, an elongation of 10–20 per cent, and a Brinell hardness of 54–62, can be formed cold to a limited extent, using a tallow or soap lubricant, or colloidal graphite in carbon tetrachloride. Cold bends can be made around very small radii. Sharper bends and deep-drawing operations must be done hot and with heated tools, preferably using annealed stock at from 400 to 500° F. A clearance of at least 0.008 in. is necessary (*The Iron Age*, Feb. 19, 1948).

Commercial **brass, bronze,** and **copper** sheet are cold rolled to tempers as follows: ¼, ½, ¾ hard, extra hard, spring hard, extra spring hard; and in light drawing, and soft drawing annealed sheets. See *American Machinist*, Sept. 26, 1934, p. 677, for composition and use of SAE brass and bronze alloys.

The light annealed material is used for shallow drawing where the material is to be polished afterward. The drawing anneal is used for deep drawing where a good surface is desired. The soft drawing anneal is used for the deepest drawing work where more than one drawing and annealing operation is required and a smooth surface not essential. One-quarter hard common brass will bend flat on itself across the grain, but only about 150 deg along the grain. One-half hard brass will bend in either direction about 80 deg with a rounding bend, and is used where both temper and bends are required or for flat work. Extra-hard material will bend across the grain about 60 deg and along the grain about 45 deg, and is used where spring propperties and slight bending are required. Spring brass will bend across the grain at 60 deg, and is used for spring work. The radius to which the metal is bent and the thickness of the material will affect the results obtained.

Speeds for Drawing

E. V. Crane[7] specifies that brass can be drawn on steel at speeds of the press crankpin up to 2,000 fpm. Steel may be drawn on steel at 35–60 fpm. Stainless steel is drawn at slower speeds to reduce the work hardening and to permit deeper draws. Magnesium is drawn at slow speeds of 7–17 fpm, the lower speeds being used on the thicker stock.

Lubricants for Work in Cutting and Forming Dies

Lubricants for **cutting and forming** are designed to prevent the metal from sticking to the die or seizure between the work and tool, to assist the flow of metal so as to prevent scratching or breaking, and to give maximum life of the die by reducing abrasion and the development of heat. The nature of the lubricant depends upon the type of die operation, that is, whether it is cutting, light drawing, or heavy or deep drawing, and upon the nature of the material as to whether it is soft and sticky, hard and brittle, etc.

Cutting and drawing lubricants are applied to the sheets or strip by the use of a brush or swab, felt pads, spraying, dipping the sheets, or passing the strips between rolls which carry the lubricants to the sheets. The latter method is most economical and usually found satisfactory in that a uniformly thin coat covers the sheet, which may disappear completely during the drawing operation or which is easily removed by a wash afterward. The swab or brush is sometimes desired to apply the lubricant locally. The ease of removing the lubricant from the part after the operation is an important factor in its selection.

In the past many materials have been used to lubricate dies. Five distinct types of cutting and drawing lubricants are in general use, as follows:

1. Water emulsions of "soluble oil."
2. "Soluble paste" with water.
3. Plain fixed and mineral oils, or compounded oils.
4. Pigment lubricants.
5. Sulphurized or chlorinated oils and bases.

Most cold-drawing lubricants are prepared in the form of **emulsions.** They consist of soaps or saponified oils mixed with fats and mineral oils. See chapter on *Cutting Fluids.* The soap base of the lubricant is of peculiar importance. It is only by means of emulsification that the unsaponified oily portion can be dispersed uniformly throughout the soapy materials and the water and be maintained in that condition. The suspension of any solid material is more readily accomplished and the compound is readily prepared for various operations by water dilution on the part of the users. **Pastes** are similar to soluble oils but are used more often as a jelly, and as such retain solids such as chalk, sulphur, and graphite in more uniform suspension.

Many lubricants consist of easily procured **oils** of the fixed and mineral type. Plain mineral oils do not possess physical properties such as film strength and adhesiveness to permit their extensive use. **Natural fats** of outstanding merit are beef tallow, degras or wool grease, lard oil, and castor oil. Beef tallow and castor oil are compounded to give very favorable properties as a drawing lubricant. Both have a high film strength or ability to keep two metal surfaces separated under pressure. The film strength of castor oil is very high compared with other oils and greases and it has a low coefficient of friction. The wetting power or ability to spread itself on the metal of castor oil appears to be higher than that of tallow. To increase the film strength of the liquid or paste lubricant as required in heavy drawing, oily solid lubricating materials are introduced up to 20–35 per cent as pigments. The function of the solid is to maintain the oil film on the work and prevent seizure through metal-to-metal contact. Natural calcium carbonate (chalk) is the most common solid so used. Other solids, such as lead carbonate, lead oleate (lead soap), zinc oxide, barium carbonate, lithopone, talc, and graphite, are added to give desired characteristics. It is by chemical treatment of these fats and solids through saponification, sulphonation, and emulsification that the favorable characteristics of each are combined.

A lubricant of a light mineral oil containing up to 4 per cent active **sulphur** possesses favorable properties for resisting metal seizure or pickup. Fixed oil bases may be made to contain up to 10 per cent active sulphur. The heavy dark base may be used as such or blended with a light mineral oil to reduce its viscosity.

Cutting dies: For light work in cutting dies, emulsions of soluble oil or soap paste are very generally used. When punching brass, copper, or German silver, a thin coat of lard oil or sperm oil is sometimes spread over the sheets before punching. These lubricants are expensive and are used only when necessary to prevent these soft metals from sticking to the dies or punches. **Sulphurized oils** are also generally used to cut tough and ductile metals such as steel, stainless steel, and Monel. White lead softened with mineral oil is sometimes used for cold punching steel. The lead carbonate often is replaced by lead oleate, which has a superior film strength, is less soluble, and is thought by some to be less likely to cause lead poisoning. The use of lead in any form should be avoided because of the danger of poisoning by absorption through the skin, by being conveyed to the mouth on food or tobacco by lead-smeared fingers, or by breathing in air containing lead dust or fumes (see *Industrial Poisons in the United States*, by Alice Hamilton, The Macmillan Co., 1925). When cutting aluminum, the sheets are often thinly coated with kerosene or an emulsion containing kerosene.

Shaping dies: Emulsions of soluble soaps and oils, used straight or when containing graphite or sulphur, are inexpensive and may be found satisfactory on most cutting and drawing operations. They are used extensively on light-gage drawing work. For heavy-duty drawing where seizure of the work to the dies is a danger and where resistance to wear is of importance, such as on steel and stainless steel and iron, low-viscosity sulphurized petroleum oils are frequently used. Heavy sulphurized base oils blended with various proportions of light mineral oil are used most generally. In **drawing** steel shells, a thin mixture of grease and white lead or lead oleate is often used. Calcium carbonate with graphite and machine oil has given very good results for drawing deep pans in one stroke.

For drawing stainless steel a heavy lubricant consisting of white lead thinned with linseed oil also is used. Frequently 5–10 per cent of flowers of sulphur is added. Whiting or lithopone may be substituted for the lead. White lead and castor oil are excellent for deep drawing.

The lubricant plays a very important part in the success of the operation of drawing or stamping **aluminum.** The best lubricant is mutton tallow mixed with a small amount of light mineral oil. Lard oil or Vaseline also gives good results.

A high-flash-point mineral oil or mixture of equal parts of beeswax and tallow is used in drawing magnesium alloy sheet.

In working sheet brass and other soft metals, emulsions of soap are used. For drawing zinc, boiling soap suds give good results.

Forging dies are best lubricated with a prepared lubricant containing graphite. Waste oils are sometimes used. The lubricant is applied with a swab and spread with an air blast. After forging, the scale is blown from the die with an air or steam blast.

SPINNING

There are two practical ways of forming pieces of sheet metal into hollow cylindrical or conical articles: with dies and by spinning. The cheaper and better method of producing work of this class in quantities is by the use of dies, as outlined above. There are many cases where it is impracticable to follow this course. When the production is small, wanted in a few days, or subject to change in design, steel dies are too costly, and spinning is resorted to. Spinning often is used to smooth out wrinkles formed in drawing operations, prepare a fine finish, or continue the forming beyond that produced in the die.

A special form of lathe has been developed for metal spinning. It is of rigid construction with no back gears or lead screw, but fitted with a driving headstock, freely rotating plate on the tailstock, and tool rest. The tool rest may be of the T form for light work with hand tools, or of the mechanically controlled compound-rest type.

Spinning lathes may be used for smoothing, necking, bulging, burnishing, trimming, wiring, or beading shallow or deep-drawn shells, pans, pots, reflectors, etc., of steel, brass, copper, aluminum, tin, zinc, etc. Examples of spinning work are shown in Fig. 47. The metal blanks or previously formed parts are held between the wood form or chuck attached to the face plate on the headstock spindle, and the rotating plate on the tailstock spindle. The chucks over which the work is spun or worked are usually made of hard wood and can be produced quickly at little expense. As the work is rotated at high speed, it is gradually worked to the shape of the chuck or form roll, using hand tools consisting of steel bars terminating in an upset polished ball or formed end, or burnishing rolls, Fig. 47. Spinning chucks are sometimes built up in sections and held together by rings so they may be taken apart to be withdrawn from the finished work. Spinning requires a high degree of skill and is hard physical work.

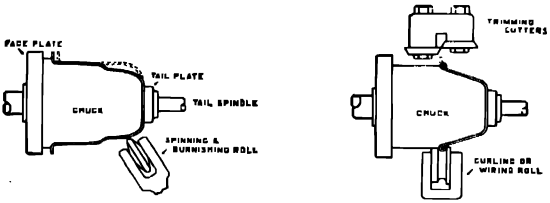


FIG. 1. SPINNING AND BURNISHING

FIG. 2. TRIMMING AND WIRING

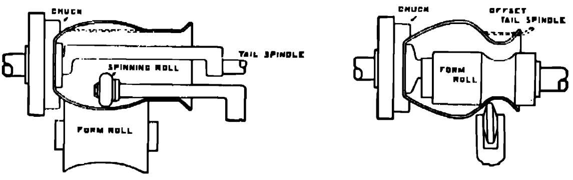


FIG. 3. INSIDE SPINNING FOR BULGING

FIG. 4. OFFSET SPINNING FOR NECKING

Courtesy E. W. Bliss Co.

FIG. 47. Illustrations of Various Operations Performed on a Spinning Lathe.

1. Spinning and burnishing the outside of a drawn cup.
2. Rotating trimming cutters properly operated to be followed by the wiring roll.
3. Form roll used for inside spinning or bulging operation.
4. Shells, first drawn straight, are bulged and then necked for proper contour.

Spinning is done commercially at **surface speeds** of 600–5,000 fpm on sheet metal up to 0.125-in. thickness. The low speeds are generally used on work diameters up to 4–6 in., 1,500–2,500 fpm on diameters of

10–14 in., and 3,000–5,000 fpm on diameters up to 4 ft. The speeds may be increased for thinner stock. Brass and aluminum may be formed at speeds slightly higher than those for zinc, copper, and silver, iron and soft steel at slightly lower speeds. Stainless steel which work-hardens must be worked at still lower speeds.

Lubricants in the form of beeswax or soap should be rubbed frequently over the work as it is being spun. Lard oil mixed with white lead is a good substitute. Either mutton or beef tallow applied with a cloth swab is good on most metals. Lead oleate is sometimes used to replace the white lead or tallow.

It is necessary often to anneal the metal at various stages of the process. After being annealed, the metal should be pickled to remove the oxide or scale from the surface to prevent pitting in the finished work. Spun work can be **finished** smooth by skimming or shaving the outer surface to remove all tool marks. The work then can be finished by polishing and buffing or with a burnishing tool.

QUESTIONS

1. What is meant by a press?

2. How does a mechanically operated press differ from a hydraulically operated press or a forging press?

3. What is meant by a forging press, and what are some of the types used for forging?

4. What is meant by a single-, double-, or triple-action press?

5. Explain each of the several ways that power may be applied to the ram of the press.

6. What are the principal types of clutches used on mechanically operated presses?

7. Name and describe several types of stock-feeding mechanisms.

8. What is meant by a knockout for a power press?

9. What is meant by a pressure attachment on a die?

10. What is the advantage of the variable-delivery pump method of operating hydraulic presses as compared with the accumulator system?

11. What is meant by a punch and die?

12. What is meant by an inverted die?

13. What is meant by a bolster plate, and how may it be prepared to facilitate interchangeable standardized die sets?

14. What are the two general classes of dies? Describe the use of each.

15. What is meant by the angular relief of a punch and die?

16. What is meant by the radial clearance of a punch and die? Explain its relation to the size of a part produced by punching or blanking.

17. Classify shaping dies.

18. Of what materials are dies made?

19. What is meant by: (*a*) a plain blanking die? (*b*) a follow die? (c) a multiple or gang die? (*d*) a compound die? (*e*) a combination die?

20. What is meant by a brake and how does it differ from a shear?

21. For what purposes and under what conditions is spinning done?

22. Explain the difference between a toggle press and a knuckle-joint press as to construction and use.

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CHAPTER XVII

THE QUALITY OF SURFACE FINISH

Most manufacturing drawings specify that certain surfaces of metal parts be finished. In few instances are the methods of finishing indicated, but more and more commonly the quality of the surface is being specified.

Surface qualities, by definition, are the physical characteristics of a boundary which separates solid substances. These qualities include such factors as the geometry of the surface in three dimensions, crystal structure, appearance, color, resistance to corrosion, hardness, and size and shape of surface flaws. Standards of surface quality now deal particularly with the geometry of the surface deviations from the nominal surface (cylinder, flat, sphere, etc.). These deviations are of three kinds: surface flaws, waviness, and roughness, all three of which can be specified in inches. **Surface flaws** are occasional irregularities, such as a scratch or slag inclusion or blow holes; **waviness** consists of widely spaced irregularities, such as wide feed marks; and **roughness** consists of finely spaced irregularities within the waves, which determine what is usually called the "finish" of the piece as shown in Fig. 1.

The ASA Standard B46.1 specifies roughness as the average deviation from the nominal surface of the finely spaced hills and valleys as a measure. Normally this height is expressed in microinches (millionths of an inch) across the surface in a direction to give the largest reading. It is recognized that this average height of irregularity is by no means a complete specification of any surface and that information as to the character of the irregularities, waviness, flaws, and other surface qualities must yet be determined. A preferred set of roughness classes with appropriate symbols which range from ¼ to 63,000 microinches, r.m.s. average, is roughly as follows:

(*a*) ¼–½ microinch, r.m.s., covers highly lapped and polished finishes used largely for laboratory work.

(*b*) 1–4 covers very fine finishing operations, such as fine grinding, honing, and lapping when done with the greatest care, for measuring instruments, gages, etc.

(*c*) 8–32 covers fine-finishing operations generally having a shiny appearance as produced by diamond or sintered-carbide turning, good finish grinding, average honing, etc.

(*d*) **63–1,000**, the lower range, covers average turning, boring, shaping, and milling operations.

(*e*) **4,000–63,000** covers the surface of rough castings and rough-machining operations.

The **lay** of a surface refers to the direction of the predominant surface marks, from the line representing the surface as observed visually. Certain symbols are used to indicate the lay direction in relation to the boundary line of the surface in connection with the surface roughness number. For example: = indicates that the predominant marks due to feed as produced by turning, shaping, planing, and milling are parallel to the edge of the surface indicated; ⊥ indicates predominant marks perpendicular to the boundary line of the surface, as for turning, slab and face milling, surface grinding, etc.; ╲ indicates that the predominant marks are at an angle as for side milling; X indicates predominant marks in two directions as in honing and lapping; C indicates approximately circular visible patterns as in facing; R those approximately radial as in Blanchard surface grinding; and M indicates multidirectional marks, such as those obtained in multiple motion lapping and honing.

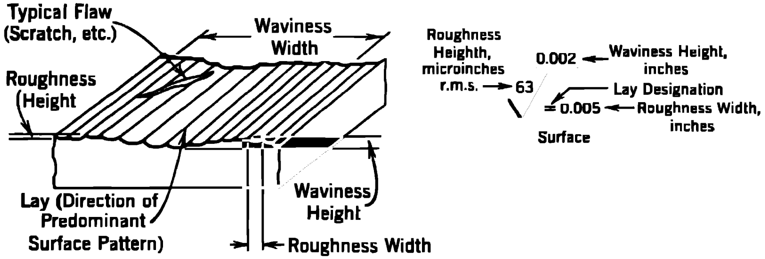


FIG. 1. A Sketch Indicating Flaws, Waviness, Roughness, and Lay of Surface Quality.

At the right the standard symbol for indicating each of these with respect to the surface is shown.

The method of applying these symbols is indicated in Fig. 1. At the upper right corner of Fig. 2 the 63 microinches, r.m.s., is obtained on the cylindrical surface having cylindrical turning feed marks.

The lower the tolerance placed on a surface, the higher the quality of the surface must be. Suggested tolerances and associated surfaces in microinches, r.m.s., in parentheses are as follows: 0.00001 (1–2), 0.0001 (3), 0.0002 (5), 0.0005 (10), 0.002 (50), 0.005 (100) and 0.010 and over, no consistent relation. The waviness height due to deflections, hard sections of the work, flaws, and the roughness width due to tool nose radii, are to be measured with the dial indicator or similar instrument.

Equipment for measuring or rating surfaces is of the following types:

1. Profile recorders draw an enlarged graph of the actual surface profile. These are laboratory instruments. The **Profilograph,** developed at the University of Michigan, uses mirrors, lenses, and a light beam. A small specimen is drawn under a pointed diamond attached to a mirror. A beam of light is reflected by the moving mirror and its path is photographed to give a true contour of the surface as illustrated in Fig. 3. The curves may be reduced to r.m.s. values.[1]

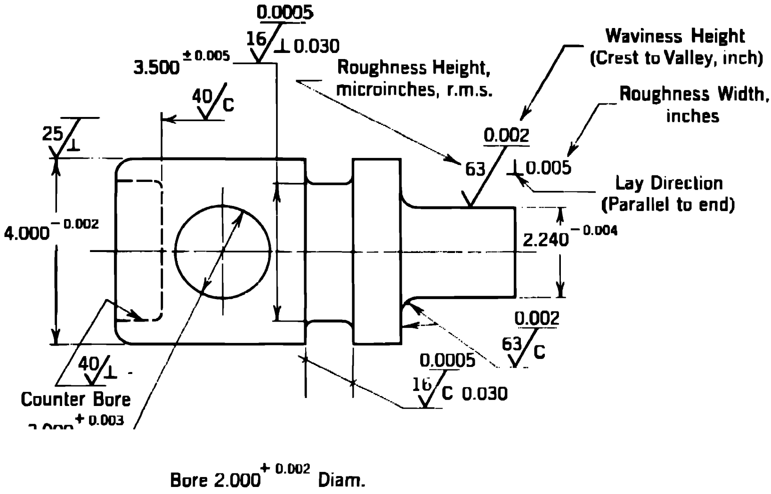
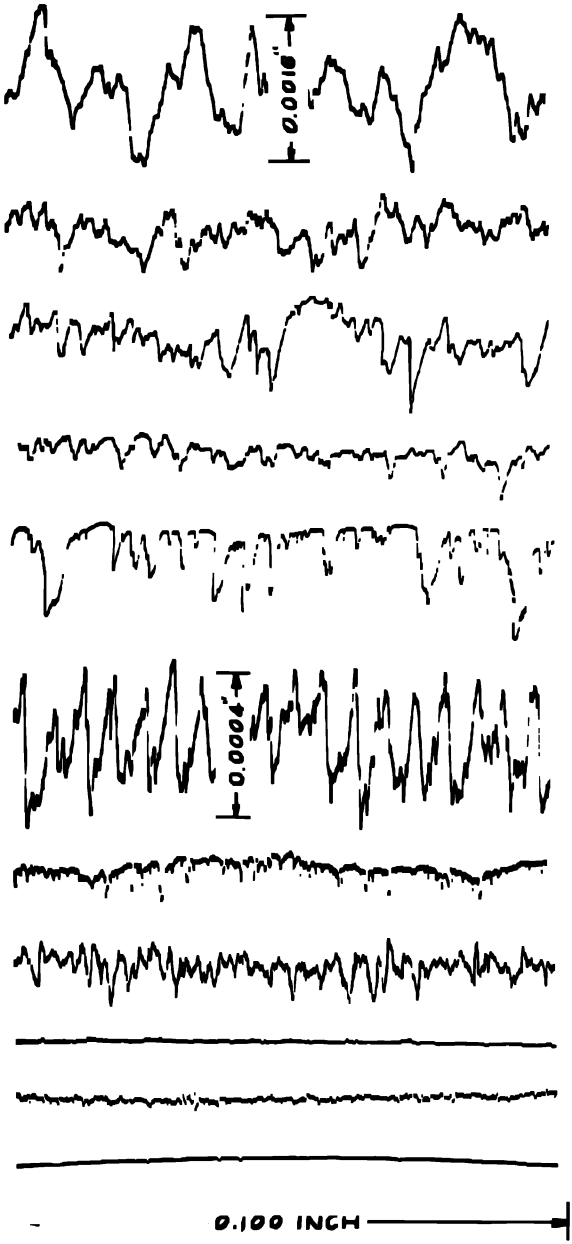


FIG. 2. A Drawing of a Part to Be Manufactured, Showing Methods of Applying the Symbols for Surface Quality.

2. With a **Profile Microscope,** several arrangements of microscopic observations with special illumination may be made to enable surface profiles to be observed directly.[13] The small area involved and the lack of a definite reading are limiting factors.

3. The **Profilometer** is a portable meter[8] which takes an automatic running average of the height of the surface irregularities and indicates this average in microinches, r.m.s., directly on a meter. The instrument is self-contained and finds direct application in the shop as well as in the laboratory. The instrument is illustrated in Fig. 4. Regardless of the smoothness of the piece, a tracer tip radius of 0.0005 in. is adequate. The Profilometer Reading Recorder is available to chart the Profilometer reading. The Proficorder, a mechanical-electronic

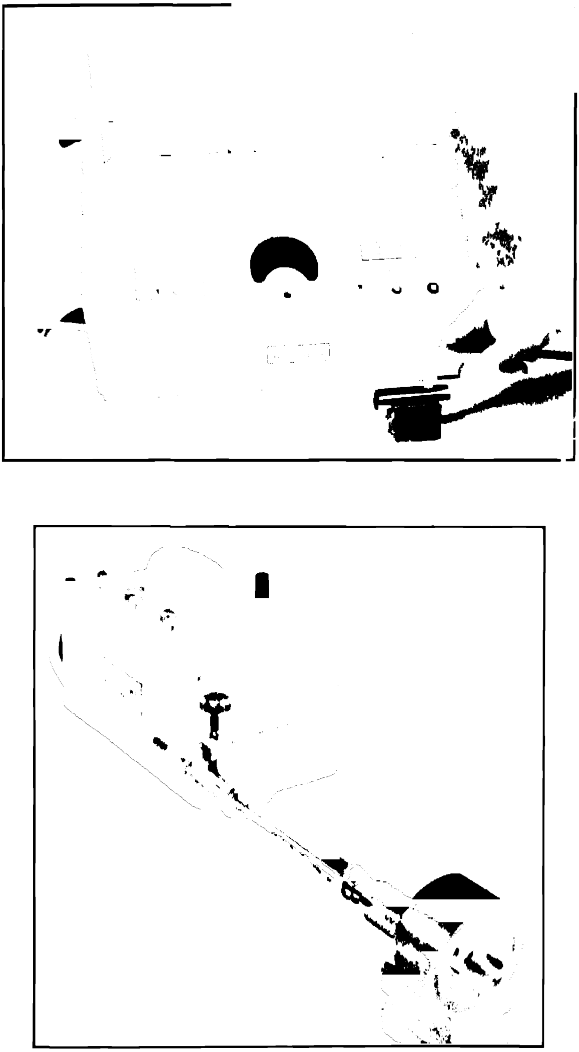


1. Rough-bored cast-iron cylinder. $500V \times 30H$.
2. Finish-bored cast-iron cylinder. $500V \times 30H$.
3. Finish-reamed cast-iron cylinder. $500V \times 30H$. 100 r.m.s.
4. Face-milled head of a cast-iron cylinder block. $500V \times 30H$.
5. Broached bronze bushing in automobile connecting rod measured circumferentially. $1{,}000V \times 30H$. 47 r.m.s.
6. Tungsten carbide bored refrigerator cast-iron cylinder. $2{,}000V \times 30H$. 85 r.m.s.
7. Rolled refrigerator cast-iron cylinder after diamond boring. $2{,}000V \times 30H$.
8. Rough-honed automobile cast-iron cylinder. $2{,}000V \times 30H$.
9. Mirror-finished automobile cast-iron cylinder. $2{,}000V \times 30H$.
10. A very finely ground aircraft steel cylinder. $2{,}000V \times 30H$.
11. A mirror-finished aircraft steel cylinder. $2{,}000V \times 30H$. 8 r.m.s.

Courtesy E. J. Abbott.

Fig. 3. Curves Indicating the Surface Finish Produced by Various Processes as Recorded on the Profilograph.

The magnification vertically and horizontally is indicated for each curve. For the $2{,}000V$, 1 in. = 0.0005 in., and for the $30H$, 3 in. = 0.100 in. The other scales are in proportion.



Courtesy Physicists Research Inc

FIG. 4. The Q Type Profilometer in a Self-Contained Case.

The dial providing various magnifications on the scale is shown at the lower left The glass master for checking the calibrating of the tracer is in the cover of the case on the top The MA-type hand tracer kept in the cover of the case at the center is shown in use by the insert at the bottom The V-type motor tracer unit and type AW tracer supported on the BA linkarm for supporting the diamond on the internal surface are shown on the bottom The two knurled knobs in front of the handle adjust the length of the stroke of the diamond on the work.

shop instrument, provides a magnified chart record of waviness, steps, and other major irregularities over a 2-in. length of trace on practically any machined surface.

4. The **Brush Surface Analyzer**[10] uses piezoelectrical crystal elements to produce a tracer record of the surface. The nature and value

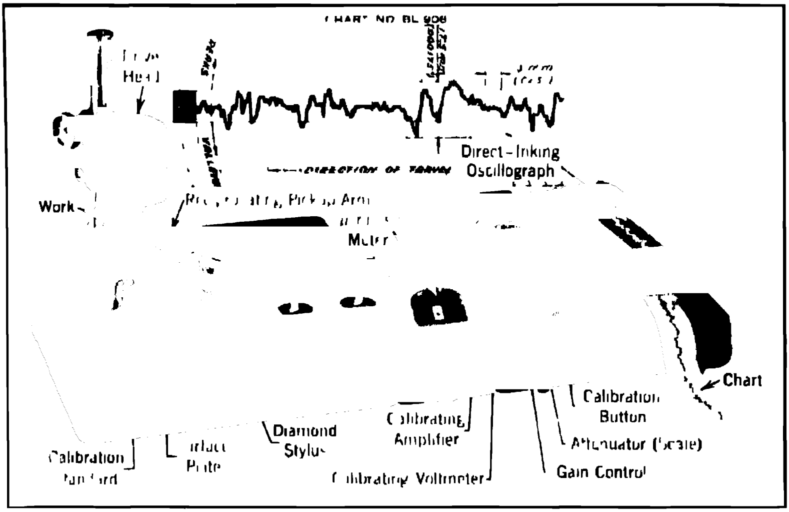


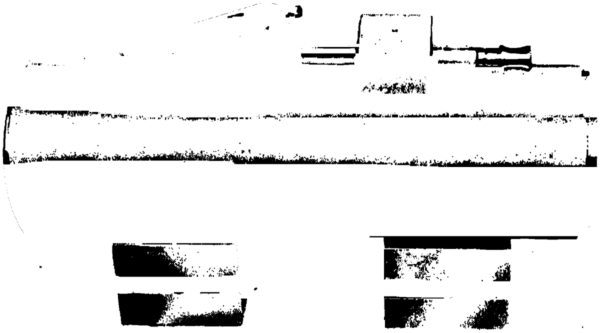
FIG. 5. The Brush Development Co. BL-103 Surface Analyzer and r.m.s. Meter.

Records surfaces from 1 to 5 000 microinches on the chart or r m.s. values on the meter. Stylus travels 1/16-in. cycle in 10 sec. Chart has 3 speeds of 1/5, 1, or 5 in per sec, obtained by different positions of the knob on the right side of the oscillograph

Attenuator provides six magnifications so that each 1-mm division on the chart is 1 μ (microinch) for 0 001 setting, 10 μ for 0 01 setting and 100 μ for 0 1 setting The insert chart shows a section of a typical trace The dark band at left is result of calibration and shows width of 10 mm. Balance of chart is one-half cycle of trace from a ground specimen, with attenuator set at 0.01 tap, and chart speed of 1 in per sec. Each millimeter of chart equals 10 μ. The maximum peak-to-valley value is 17 5 mm (0 000175 in), but the average from the centerline is about 4-mm spread, or 0 000040 μ, or 14 microinches, r m s.

of the surface in microinches are recorded on a chart for study. The value in microinches, r.m.s., may also be read directly on a scale of the "RMS" meter shown in Fig. 5. A profile chart, whether an accurate reproduction as obtained on the Profilograph, Fig. 3, or a close reproduction as obtained on the Proficorder and as represented by the Brush chart in Fig. 5, permits the evaluation of (*a*) extreme heights of peaks and depths of valleys in microinches; (*b*) average of largest peaks and valleys in microinches; (*c*) average total height of all irregularities in microinches; (*d*) r.m.s. value of all irregularities in microinches from a centerline drawn through the profile curve or the mean surface. Each of these averages will vary for surfaces of different characters. If the surface profile is rectangular in form, the r.m.s. average value would equal the arithmetical average. If it is a sine curve, the r.m.s. average is 11 per cent greater than the arithmetical average. The r.m.s. average is the value most generally associated with roughness measurement.

5. The Roughness Operated Displacement Integrator, known as "**RoDi**," is a device by which a diamond point is drawn a distance of 1 in. over the surface to be measured, while the total vertical travel of the diamond as it moves up and down over the feed marks or smaller variations from the plane is indicated on a graduated dial.



Courtesy Federal Products Corp., Lincoln Park Industries, and D. E. Williamson.

FIG. 6. The RoDi Surface Measuring Instrument, Shown Set Up for Measuring the Surface Quality of a Small Cylinder.

The dial reading for a 1-in. traverse of the diamond is obtained.

This reading represents the surface quality, and, while it does not give readings equal to those of other measuring devices, they are proportional. This instrument is of value in comparing surfaces above 30 microinches, r.m.s. Its greatest use is probably that of comparing surfaces of a given accepted specimen with parts being made in current production by the same processes. The instrument is drawn over the work at speeds between ½ and 1 in. per sec. The instrument with its support is shown in Fig. 6, in position for measuring a circular pin in turn supported on two V blocks.

6. The Comtor quick scanning **Surface Comparator**, Fig. 7, presents a method of rapidly comparing the surface finish of parts with a standard. A photoelectric scanning head, a self-contained amplifier with calibrating controls, and a finish meter provided with tolerance markers rate the work surface based on the amount of light projected

to and reflected from it. Surface standards are used to set the machine for a standard finish.

7. A simple device known as **Fax Film**[7] produces a replica of the surface. This consists of putting a drop of acetone on the surface to

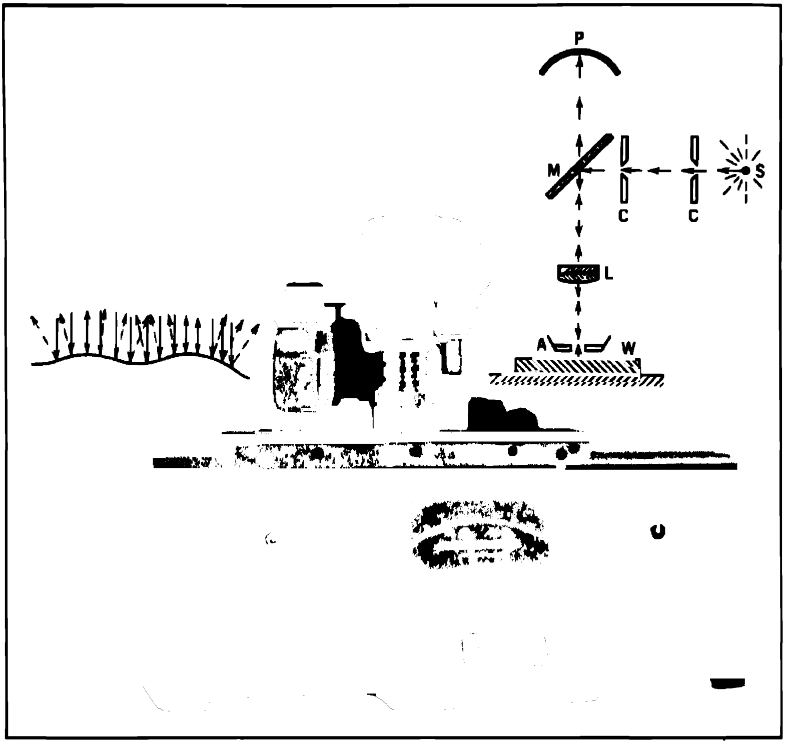


FIG. 7. The Comtor Co. Model 6 Surface Comparator Is Based on Reflection of Light *S* Projected on the Work Surface *W*, to a Photoelectric Cell *P*.

The developed e.m.f. is amplified on the scale to read the per cent of standard. Zero reading is obtained from dull black area of a plastic in which a platinum surface rating 100 per cent is mounted. All surfaces should be cleaned with Keton in a special cleaning device, push-button controlled, built into the unit. The optical system is diagrammed at the upper right, and the nature of the reflection from the greatly enlarged surface is shown at the left. The dashed arrows represent lost light.

be read. A piece of acetate film is placed over the acetone and pressed in place with the heel of the hand. In a matter of seconds the acetone causes the acetate film to soften and flow into the most minute serrations in the surface. In another half minute the acetate film hardens and may be lifted from the surface. An exact replica or facsimile of the surface of the material is thus obtained on the transparent acetate film. This film is then mounted in a suitable paper holder so it may be projected on a screen at any convenient magnification for study as shown in Fig. 8.

8. Another method of evaluating surface roughness is by comparing the machined surface, whether it be lapped, honed, ground, turned, or milled, with **standard specimen blocks**[1] finished in the same manner to represent the roughest surface acceptable under each heading or surface-finish designation in microinches, r.m.s., of 1, 2, 4, 8, 16, 32, 63, 250, and sometimes 500. A typical set of flat blocks is shown in Fig. 9. Similar sets are made by other companies and the U. S. Army Ordnance. The Norton Co. manufactures a set of 8 cylindrically ground steel specimens. Comparisons of the work surface with that of the blocks is made visually or by scraping with the fingernail. These are admittedly limited in their satisfaction, but still fill a definite need in bringing the vendor and purchaser to a common understanding.

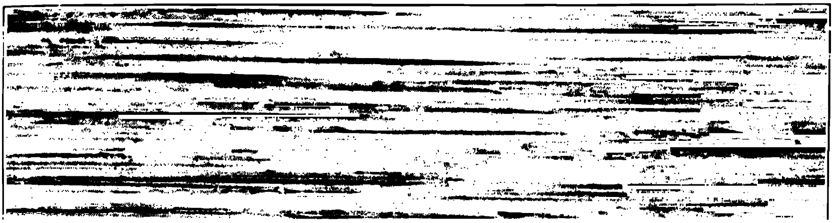


FIG. 8. A Fax Film Photomicrograph, Showing a 30-microinch, r.m.s., Surface Quality as Ground on a Cylindrical Crankshaft Bearing of 1045 Steel (100×).

9. A test for **bearing area** of a surface may be made by determining the per cent of contact area of the surface with a master surface coated with prussian blue, red lead, etc.

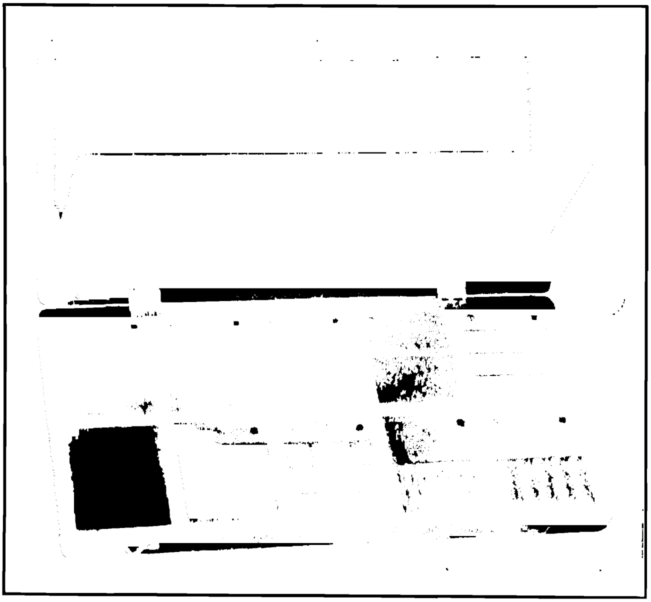
10. The nature of very smooth surfaces may be determined by studying **light-interference bands** produced by bearing an optical flat on the surface.

11. Relatively rough surfaces may be compared by observing the **reading of a test indicator** passed over the surface while its base is supported on a master surface.

12. **Photographs** taken of a surface at a magnification of 1×–10× often show the character of a surface to good advantage.

Profilometer readings in microinches, r.m.s., were obtained on surfaces turned on a 2-in.-diam. bar under various conditions for 6 different materials. For a high speed tool ground to a shape of 8, 14, 6, 6, 10, 15, $\frac{3}{64}$, when operating at 75 fpm, $\frac{1}{16}$-in. depth of cut, and 0.020 ipr, the surface finish produced by different cutting speeds was

500–220 at 25 fpm, improving from 250 to 200 at 350 fpm. All the metals were in this range, but the 24ST aluminum, free-cutting brass, and cast iron gave the best finishes. When the feed and depth are varied, the surface finish for the various metals is as shown in Fig. 10.



Courtesy General Electric Co.

FIG. 9. The G.E. Set of 10 Metal Blocks, Representing 25 Lapped, Ground, and Machined Roughness Surfaces.

These specimens enable engineers or designers to specify by a symbol as f_1, f_2, · · · f_8 the maximum roughness allowed on each particular surface of the part. The range of surface quality in microinches, r.m.s., is from 4 for f_1 to 2,000 for f_8. The block is to be compared with machined surface visually or by scraping with the fingernail. The case cover is partly open to show the reference chart.

This indicates that the best finishes are obtained at the lowest feeds for this tool with the 15-deg end-cutting-edge angle regardless of the depth of cut.

When the nose radius was changed under these conditions the following r.m.s. values were obtained: 800–500 for a sharp nose; 400–100 for $\frac{1}{16}$-in. nose radius; 200–60 for a $\frac{1}{8}$-in. radius; and 175–60 for $\frac{3}{16}$-in. and $\frac{1}{4}$-in. radius. The lower values were obtained on the harder metals such as 24ST, free-cutting brass, and cast iron, while the poor finishes were obtained on the SAE 1035, SAE 3140 and 2S aluminum.

Table 1 gives limiting values of surface quality in microinches, r.m.s., which may be obtained by many processes. The designers should know the surface quality required on various surfaces and the manufacturer must know how to obtain this quality at the lowest possible cost. Close tolerances and allowances must be accompanied by high surface quality. The cost of manufacture is generally higher for work made to low tolerances and high surface quality.

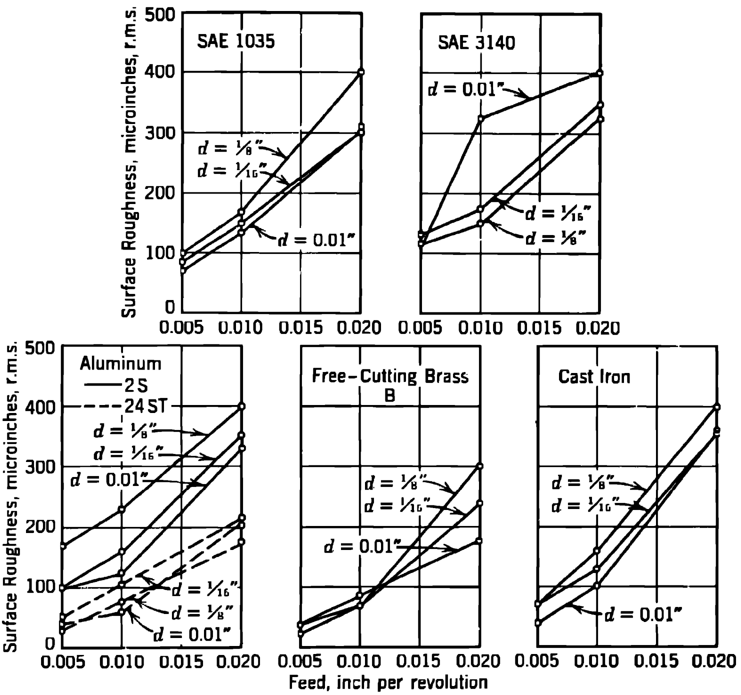


FIG. 10. Profilometer Readings in Microinches, r.m.s., of Turned Surfaces on 2-in.-diam. Bars of Six Metals.

"Mo Max" high speed steel tools 3/8 in. sq were ground to a shape of 8, 14, 6, 6, 10, 15, 3/64 in. The cutting speed was 75 fpm in all cases as the feed was varied for each of three depths of cut.

QUESTIONS

1. What is meant by (*a*) roughness; (*b*) waviness; and (*c*) lay?
2. How may surface roughness be indicated in microinches, r.m.s.?
3. How do these values agree with those obtained on the Brush Analyzer graph?
4. Name several methods for evaluating surface finish.
5. How is the Fax Film replica used to assist in maintaining surface-quality standards?

TABLE 1. SURFACE QUALITY OF A VARIETY OF SURFACES USING A PROFILOMETER WITH A MOTO-TRACE

Material and Shape	Finished by	Surface Finish, r.m.s.
1. Aluminum cup	Cold rolled and drawn	5-6
2. Aluminum casting	Faced milled	12-150
3. Brass, cold-rolled sheet	Cold rolled and drawn	11-12
4. Brass pin	Form turned	12-32
5. Bronze bushing	Precision bored	24-60
6. Boron carbide plug gage	Diamond lapped	0.8
7. Cast-iron flat	Blanchard ground, placed radially	10-15
8. Cast-iron flat	Blanchard ground, placed tangentially	15-20
9. Cast-iron flat	Surface ground, straight wheel (par.)	10-11
	(per.)	25-30
10. Cast-iron flat	Shaper, wide feed-finish cut	150
11. Cast-iron flat	Shaper	
	0.004 feed	120
	0.013 feed	240
	0.023 feed	400
12. Cast-iron flat	Helical slab mill 0.050 depth, 0.004 fpt	180
13. Cast-iron No. 4 Morse taper	Cylindrically ground with 60-grit wheel and emulsion	6-7
14. Plastic fountain-pen cap	Molded and buffed	2-3
15. Sintered-tungsten carbide plug gage	Diamond lapped	0.5-0.85
16. Steel, SAE 1030 die-forged orthopedic brace	Rough polish, 50 grit	130-140
	Second polish, 110 grit	60
	Third polish, 220 grit and grease	25
	Grease and emery cake	15-18
	Color buff — crocus	9-10
17. Steel tubing	Cold drawn	9-11
18. Steel, flat cold rolled	As cold rolled	60-70
19. Steel (low-carbon), flat	Surface ground, straight wheel	25-30
20. Steel, flat cold rolled	Blanchard grind	45
21. Steel bar SAE 52100, 2 in. round, hardened, 63 Rock. C	Cylindrical ground	
Work speed, 320 rpm, 166 fpm	80-grit wheel, 5% emulsion	28
Wheel speed, 6,500 fpm	150-grit wheel, 5% emulsion	29
In-feed per pass, 0.001	180-grit wheel, 1% emulsion	58
Table feed per rev of work, 0.081	180-grit wheel, 5% emulsion	42
22. Steel, round bar, flat cold rolled	As cold drawn	8-32
23. Steel, flat cold rolled	Slab milled	50-90
24. Steel, flat cold rolled	Face milled	
	Light feed	120
	Heavy feed	270
25. Steel plate	Blank or punched	100-500
26. Steel plate	Die shaved	6-63
27. Steel forging	Broached	16-63
28. Steel forging	Broached and burnished	3-8
29. Steel cylinder, $\frac{7}{8}$ in. diam.	Bored	63-250
30. Steel cylinder, $\frac{7}{8}$ in. diam.	Honed with 180 grit	16-50
31. Steel cylinder, $\frac{7}{8}$ in. diam.	Honed with 500 grit	2-12
32. Steel cylinder, piston pin, gage, etc.	Lapped	1-6
33. Steel, 75-mm high-explosive shell	Turned with $\frac{1}{4}$-in. radius and 0.030-in. feed	250
34. Steel 75-mm high-explosive shell	Turned and painted	210
35. Steel plug gage, chromium plated	Lapped	0.5-2
36. Zinc carburetor bowl	Die cast	24-63

6. Why does the Norton Co. furnish cylindrically prepared surface-quality specimens while the Army Ordnance furnishes flat specimens?

7. Approximately what surface finish, in microinches, r.m.s., should be provided on (*a*) chrome-plated steel plug gage; (*b*) cold-rolled aluminum sheet; (*c*) cold-drawn steel tubing; (*d*) a broached hole in a steel forging; and (*e*) a cylindrically ground hardened steel?

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CHAPTER XVIII

MEASURING AND GAGING

MEASURING INSTRUMENTS

Standards

In machine-shop practice, the accuracy to which work can be produced depends upon the accuracy to which it can be measured. This discussion will be confined to the measurements of linear and circular dimensions, angles, and shapes.

Measurements of length are expressed in terms of some definite unit. When this unit is represented physically by some object, materials and temperatures are involved.

The Meter — The Metric Standard of Length

The fundamental metric unit of length, the meter, is the distance between two fine lines graved on a platinum-iridium bar at the International Bureau of Weights and Measures, Sèvres, France, when this bar is at a temperature of 0° C. This bar is known as the International Prototopye Meter. The unit, the meter, sometimes called the international meter, is the fundamental unit of length on which the United States inch is based. Copies of this meter of duplicate construction and material have been made, calibrated against the original, and distributed to the several countries subscribing to the Bureau. Copies, numbered and known as National Prototype Meters Nos. 21 and 27, are held at the U. S. Bureau of Standards, Washington, D. C. They are of correct length at 0° C. The international meter equals 1,553,164.13 wave lengths of red light from cadmium vapor, as advocated by Fabry and Perot in 1906, at 760 mm of Hg, 15° C, and through dry air. This value is correct to one in ten million.

Standard Temperature

The International Committee on Weights and Measures on April 10, 1931, adopted 20° C (68° F) as the normal temperature for adjustment of industrial standards for length measurements. At this temperature, the instruments should be the correct size.

The Inch — The United States Unit of Length

In 1866, the United States Congress established the relation between the yard and the meter as

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3{,}600}{3{,}937}$$

from which

$$1 \text{ meter} = 39.37 \text{ in.}$$

and

$$1 \text{ in.} = 25.4000508 \text{ mm} = 39{,}450.369 \text{ light wave lengths}$$

The difference between the British inch of 25.39998 mm and the United States inch is so small that it may be neglected in machine-shop practice.

The American Standards Association on Oct. 31, 1932, approved the adoption for United States industrial practice of the simple ratio

$$1 \text{ in.} = 25.4 \text{ mm}$$

A difference of two millionths of an inch per inch of length now prevails between this simple ratio and that established by Congress.

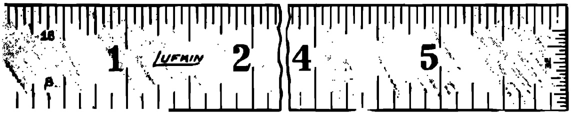
Definition

In general, shop measurements may be divided into two general classes: direct and comparative. A direct measurement is one in which the actual size is determined. A comparative measurement is one to determine the difference in size between similar or mating parts. In general, a comparative measurement is much quicker to make than a direct one.

Types of Measuring Instruments

Measuring instruments are used to make a direct or true measurement. They are scaled, or graduated and dimensioned. Four principles are used in measuring: the **scale** (linear or circular), the **micrometer,** the **Vernier,** and the **indicator.** The interferometer is the basic direct-measuring instrument. It measures distances in terms of wave lengths of light, as described below. The microscope, reflected light, and light waves are used for measuring and gaging accurately, as described below under *Optical Measuring Instruments and Comparators.*

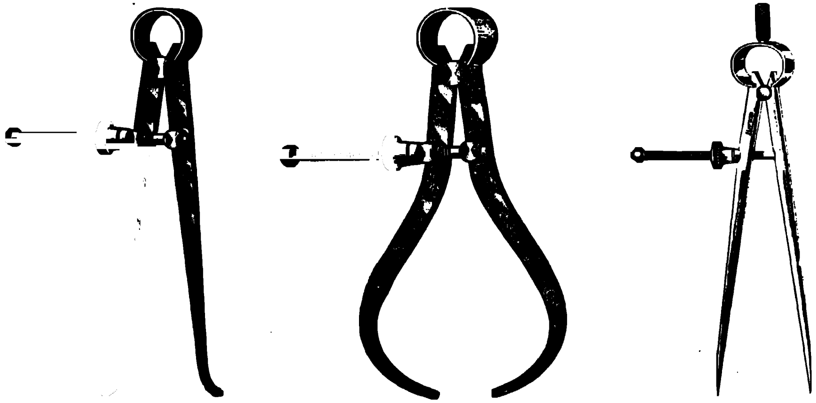
Figure 1 illustrates a simple type of **steel rule** commonly used by machinists. It is graduated on one side in $\frac{1}{32}$- and $\frac{1}{64}$-in. divisions and on the other in $\frac{1}{8}$- and $\frac{1}{16}$-in. divisions. Scales of this type are made in various lengths and sections. Some are stiff, others thin and flexible. Some are provided with a beveled edge, or with a short right-angle hook attached to one end to facilitate taking measurements over rounded corners, or from an edge, as through the bore of pulleys. The hook may be used as a stop for one leg of dividers or inside calipers while the size is being read.



Courtesy Lufkin Rule Co.

Fig. 1. Machine-Divided Spring-Tempered 6-in. Steel Rule Graduated in $\frac{1}{32}$ and $\frac{1}{64}$ of an Inch.

Rough measurements are frequently made by adjusting the **calipers,** shown in Fig. 2, to fit the work and then reading the caliper setting on a scale. A split or sliding nut is sometimes provided on the screw to save time in making adjustments. **Hermaphrodite calipers,** used principally in laying out work, locating centers, etc., have one adjustable point and one leg turned inward at the end. The hooked leg bears against the edge of the work, while the point scribes locating lines on chalked, colored, or plated surfaces. Intersecting arcs on bosses or on the ends of bars help to locate centers which then may be punched, centered, or drilled. **Spring dividers** have hardened points and are used in laying out or scribing lines to proper dimensions on the surface of work to be machined.



Courtesy Lufkin Rule Co.

Fig. 2. Inside and Outside Spring Calipers, and at the Right a Toolmaker's Spring Dividers.

Scales of 6-, 12-, or 24-in. length are frequently provided with a center head, **protractor**, and square, as shown in Fig. 3. The center head is used for marking diameters on the end of a cylindrical bar, the intersections of which locate the center.

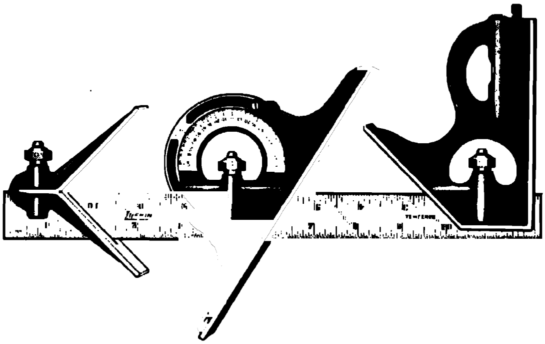
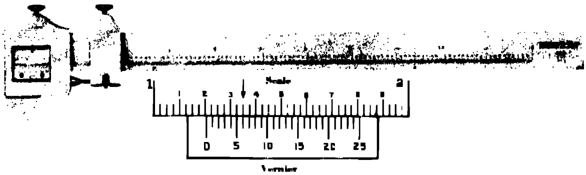


FIG. 3. A Lufkin Combination Set Consisting of a Hardened-Steel Blade Carrying a Square Head on the Right End, a Center Head on the Left, and a Reversible Protractor in the Center.

The principle of the **Vernier** is illustrated by the 13-in. Vernier caliper used for inside and outside measurements, Fig. 4, and the gear-tooth Vernier, Fig. XIV-31. It also is used in depth and height Verniers and on protractors. Outside measurements are taken between the jaws, and inside measurements over the jaws, Fig. 12. When inside measurements are taken, the combined thickness of the two jaws, such as 0.250 in. for the 6-in. Vernier and 0.300 in. for the 13-in. Vernier, should be added to the Vernier reading. The fixed scale, as shown by the insert, is graduated into inches, each inch into tenths (0.100), and

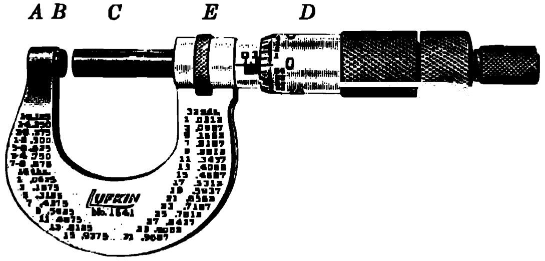


Courtesy Brown and Sharpe Manufacturing Co.

FIG. 4. The Vernier Caliper with a 13-in. Scale.

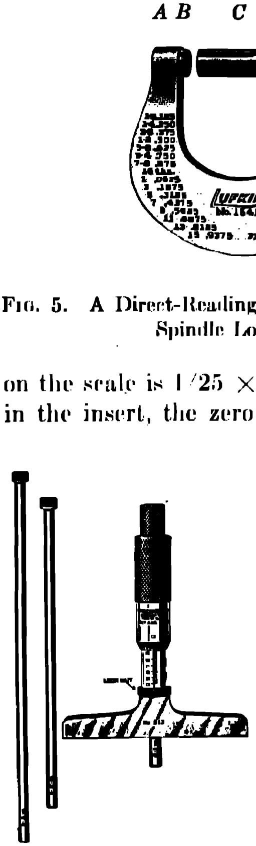
The insert shows an enlargement of the Vernier scale which reads 1.206 in. When making internal measurements, 0.300 in., corresponding to the width of the two jaws, must be added to the Vernier reading.

each tenth into quarters, making 40 divisions of 0.025 in. each to the inch. The auxiliary slide or Vernier is graduated into 25 equal parts and corresponds in extreme length with 24 divisions (24/40) on the scale. The difference then between a division on the Vernier and one on the scale is $1/25 \times 1/40 = 0.001$ in. To read the scale as shown in the insert, the zero on the Vernier scale indicates 1.2+ in. It is seen that the sixth line on the Vernier scale corresponds to a line on the main scale, thus making 0.006 in. to be added to the 1.2+, giving a Vernier reading of 1.206 in. Divisions other than 25 to 24 are frequently used, such as 20 to 19, 10 to 9, etc.



Courtesy Lufkin Rule Co.

FIG. 5. A Direct-Reading 0-001-in. Micrometer Caliper of 0–1-in. Capacity with Spindle Lock, *E*, and Constant-Torque Ratchet, *F*.

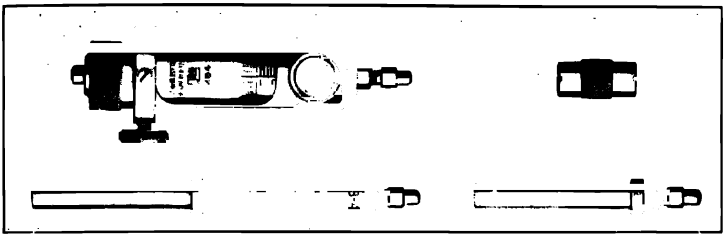


Courtesy Lufkin Rule Co.

FIG. 6. A Micrometer Depth Gage with Three Measuring Rods Which Permit the Measurement of Depth of Holes and Projections from 0 to 3 in. by 0.001 in.

The **micrometer** principle applied to a zero- to 1-in. micrometer caliper is shown in Fig. 5, to a depth gage in Fig. 6, and to an inside micrometer in Fig. 7. The micrometer principle involves a linear and cylindrical scale. The hub of the micrometer, Fig. 5, has a linear scale with each inch divided into tenths and each tenth divided into four divisions of 0.025 in. each. The spindle and screw *C* carry the sleeve *D*. The screw has 40 threads per in. The left end of the sleeve is graduated circumferentially into 25 equal divisions. For one turn of the sleeve it advances 0.025 in., so that each division on the sleeve represents 0.001 in. For the zero reading, the zeros on the hub and sleeve scales coincide. The reading of the micrometer is 0.125 in.

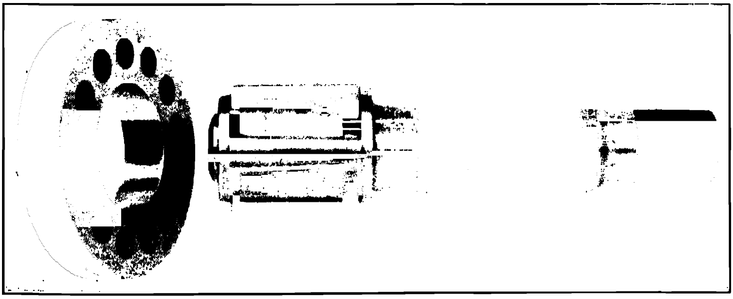
Some micrometers have direct-reading scales so that the reading is indicated in numbers, rather than being left to the judgment of the operator. Others, with a third scale like a Vernier around the sleeve, of 10 spaces to 9 on the scale, give direct readings to 0.0001 in. Most sizes have a limiting range of the micrometer of 1 in., with a caliper capacity of 1 in., such as 0 to 1 in., 1 to 2 in., 2 to 3 in., etc. Frequently, to increase the capacity of a given tool, extra rods are furnished, as shown in Figs. 6 and 7.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 7. An Inside Micrometer of 2–4-in. Capacity.

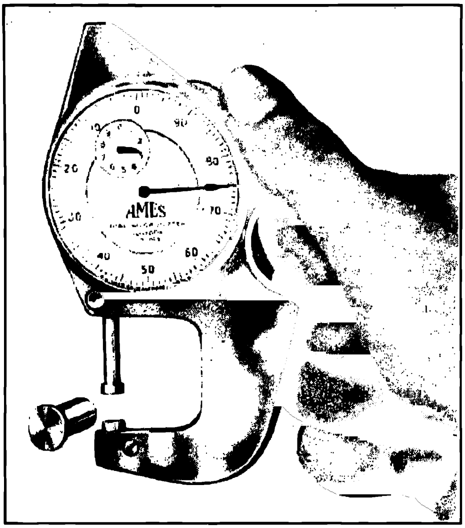
The 2–3-in. stem may be replaced by a 3–4-in. stem. Six stems for a total range of 2–8 in. are furnished. The micrometer sleeve has a ½-in. movement. A 1-in. capacity is obtained for each stem by using the ½-in.-long knurled collar. The reading shown is 2.125 in.



Courtesy John Bath and Co.

FIG. 8. Internal Micrometer Plug and Master Reference Ring.

The small knurled **ratchet stem** on the end of the handle, Fig. 5, may be used to advance the spindle against the work. When a predetermined pressure is obtained, a small ratchet slips, thus insuring that the same degree of pressure always is used. Micrometers are made in many different styles and sizes. The micrometer is often used to measure the size of screw threads by measuring over three wires, as shown in Fig. 35. The anvil and spindle ends are sometimes formed for specific purposes, such as being pointed to a 60-deg included angle for measuring screw threads, Fig. 26*F*. Means are provided for adjusting micrometer calipers for accuracy or for wear on the faces of the anvil and spindle.



Courtesy B. C. Ames Co.

FIG. 9. A Dial Indicator Measuring Directly to 0.001 in. on Caliper Gage.

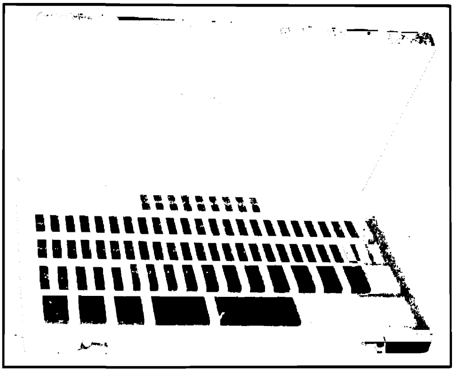
The **internal micrometer plug,** Fig. 8, was developed to measure holes accurately. It is made in sizes from ½ in. to 8 in. diam. Each tool has only a small range. The size is read from the single dial on the knurled handle which is graduated to 0.0001 in. The four inserts are ground and lapped while contracted below the minimum size. Each insert at normal size position bears against the hole in straight-line contact. These surfaces are sometimes threaded when the tool is used for accurately measuring internal threads.

Engines for making linear scales are in use. Others are available for dividing circles as used on surveying and astronomical instruments having an error of division less than 1 sec of arc.

Indicators are sometimes used for making direct measurements, although more often for gaging as described below under *Indicating Gages*. A small direct-measuring instrument employing a dial indicator is shown in Fig. 9. Thousandths of an inch are read on the large scale and tenths on the small.

Master Gage Blocks

The importance of regional, national, and international standards for industrial measuring is brought prominently to the fore in connection with war work. The making of component parts of an assembly in different geographic locations frequently emphasizes inconsistencies of standards. In present commercial practice, measurements to 0.0001 in. are frequently insisted upon. Standards of an exceedingly high degree of accuracy are essential for uniformity in this work.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 10. The Johansson Gage Block Set No. 1 in a Case.

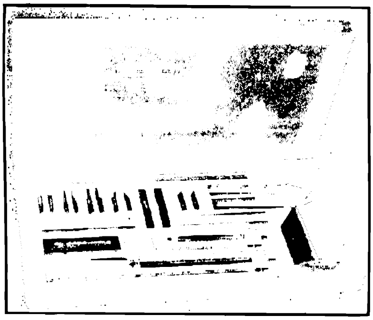
This set consists of 81 blocks in four series which make over 120,000 different size combinations in 0.0001-in. steps from 0.1001 in. to 12 in.

The first series consists of 9 blocks 0.1001–0.1009 in. by 0.0001-in. steps. The second series consists of 49 blocks 0.101–0.149 in. by 0.001-in. steps. The third series consists of 19 blocks 0.050–0.950 in. by 0.050-in. steps. The fourth series consists of 4 blocks 1.000–4.000 in. by 1.000-in. steps.

These sets are made in three standards of accuracy, as follows: working set B with allowable error of 0.000008 in. per in., inspection set A with 0.000004 in. per in., and the laboratory set AA with 0.000002 in. per in.

The accuracy of the Vernier, micrometer, and indicating and optical measuring instruments should be checked frequently with master gages. Sometimes an accurate plug or ring is furnished with Verniers and micrometers for this purpose. So-called master gage blocks with very hard, smooth, flat, and parallel surfaces in the form of Johansson gages, Fig. 10, first made in Sweden, are now made by Brown and Sharpe Manufacturing Co. The Hoke gages, Fig. 15, made by Pratt and Whitney, and others of a similar type are now available in single units of any size and various shapes, or in different standard sets.

Master gage blocks are used in checking measuring instruments, as in Fig. 13*A*, setting indicating gages and optical comparators to zero, as in Fig. 18, and frequently in locating work for measuring, as with the sine bar in Fig. 15*A*, and the compound cross-slide table in Fig. 17. A set of accessories for use with the blocks is shown in Fig. 11. Figure 12 shows how the blocks may be used with the holder and jaws for making male or female gages. The holder also may be attached to the foot block for forming a height gage or scriber.



Courtesy Brown and Sharpe Manufacturing Co.

FIG. 11. The Johansson Gage Block Accessory Set No. 47 of 22 Pieces in Case.

2 — 0.100 × 2 jaws
2 — 0.200 × 2 jaws
2 — 0.250 × 2 jaws
2 — 0.500 × 3 jaws
2 — 0.750 × 5 jaws
2 — ¾ × 6 jaws
1 — 2⅝ adjustable holder
1 — 5¾ adjustable holder
1 — 9¾ adjustable holder
1 — center point
2 — tram points
1 — scriber
1 — ½ × 3 triangular straight edge
1 — ¾ × 5½ triangular straight edge
1 — 1.375 foot block

Blocks of master gage accuracy made to various included angles are also provided for the accurate gaging and tool-making industry. The Webber angle gage blocks illustrated in Fig. 13*B* show two of the blocks from the set No. 16A by which angles ranging from 0 to 99 deg in steps of 1 sec can be obtained. There are six blocks in the degree series of 1, 3, 5, 15, 30, and 45 deg; five blocks in the minute series of 1, 3, 5, 20, and 30 min; five blocks in the seconds series of 1, 3, 5, 20, and 30 sec. Sets with fewer blocks are also available.

Surface plates, Figs. 14 and 15*B*, used as flat surfaces for reference planes in setting up instruments or checking dimensions, are made in a wide variety of sizes and shapes and of many materials. The most common surface plate is of cast iron deeply ribbed on the

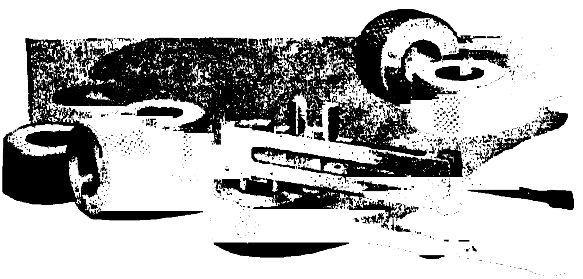


FIG. 12. The Johansson 5¾-in. Holder Set Up with Blocks and Jaws to Form Two Plug Gages for Inspecting Ring Gages.

underside having three feet for support. They are usually scraped as mentioned in the chapter on grinding. They may be surface ground or lapped by the use of abrasives. The **Toolmaker's flat,** usually 5 in. in

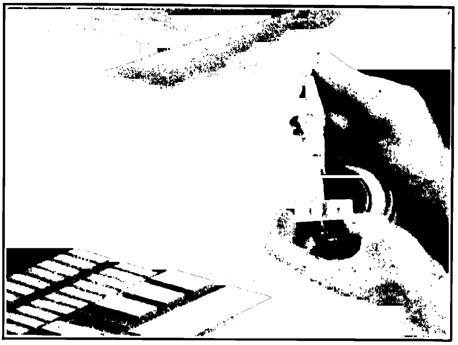
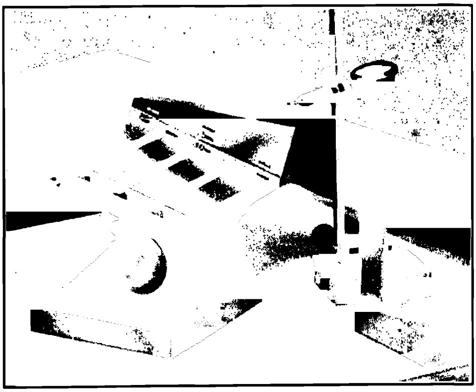


FIG. 13A. Checking a Micrometer Caliper for Accuracy with a Johansson Gage Block.



Courtesy Webber Gage Co.

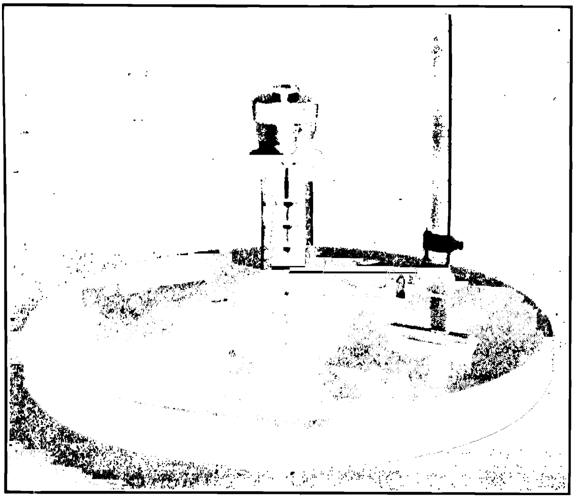
FIG. 13B. Angle Gage Blocks Used to Set Up a Toolmaker's Universal Angle Plate to an Angle of 14 deg 30 min.

The surface test indicator should show no deflection as the contact point is moved along the upper surface of the block if that surface is parallel to the face of the Vitrolite surface plate.

diam. and ⅞ in. thick, is made of hardened steel accurately lapped. Other plates are made of glass, granite, Vitrolite, or ceramic as illustrated in Fig. 14.

For surface-plate work, a large variety of accessories is required.

These consist of hardened and ground steel parallels, cast-iron box parallels, universal right-angle irons, Toolmaker's knee, Toolmaker's adjustable knee and adjustable angle plates, measuring irons, hardened steel squares, universal squares, cylindrical squares, V blocks, scales, surface test indicators, Vernier height gages, precision levels, and many other types of instruments.



Courtesy Norton Co.

FIG. 14. The Norton Ceramic Surface Plate of Circular Form Having Exceptionally Good Wear Resistance.

A Vernier height gage carrying a small dial indicator is used in transferring dimensions from the flat gage to the Pla-Check surface height gage.

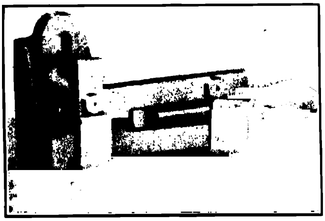


FIG. 15A. Johansson Gage Blocks Used in Setting Up a Taft-Pierce Sine Bar on the Sine Bar Fixture for Measuring the Taper of an End Mill.

A **sine bar** used to measure angles is illustrated in Figs. 15A and 15B. It consists of hardened and accurately ground disks of equal diameter attached at or near the ends of a bar, both edges of which are parallel to the line joining the centers of the disks. The center distance of these disks is an exact 5 or 10 in. The correct height to raise one end above the other to produce a given angle with the horizontal surface plate is found by multiplying the length of the bar by the sine of the angle. Thus, a 30-deg angle is obtained by raising one end of a 10-in. bar 5 in. above the other, as 10 × sin 30 deg = 5. The sine bar can be built into various tools for laying out and machining angular work, or into fixtures for measuring.

Courtesy Pratt and Whitney Co.

FIG. 15*B*. Hoke Precision Gage Blocks Set No. 81E, Containing 81 Blocks.

They are being used in a typical setup on a large, heavy surface plate, showing a toolmaker checking the pressure angle and spacing of the teeth of a Maag gear cutter by comparing the surface of the cutter tooth against the height of a stack of blocks of the required dimension. The surface gage is equipped with a beam indicator which furnishes a sensitive touch and also indicates any variation in size. The cutter is clamped to a toolmaker's knee resting on a sine plate.

Compound angles are set up or measured on the compound sine plate, Fig. 16, having two sine plates at right angles to one another. These are made in several sizes.

Optical Measuring Instruments and Comparators

Optical methods of measuring and inspecting are now being used extensively where high precision is required. Microscopes and magnifiers have been designed purposely for the work shop. When a part is to be made to a tolerance of, say, 0.001 in., the toolmaker is called upon to work to an accuracy of approximately one-fifth of this amount. This means that tools and gages are very commonly made to an accuracy of 0.0001 or 0.0002 in.

The **Toolmaker's microscope,** Fig. 17, designed to show objects in their natural aspect and movements in the correct direction, instead of inverted, is commonly used by toolmakers and machinists in measuring and checking tools, gages, etc. It consists essentially of a microscope mounted adjustably on a vertical column and located over a compound cross-slide table or stage mounted on the base of the instrument. The micrometer eyepiece has a protractor in its focal plane. Cross lines intersect at the center of the field so angles of screw threads can be read on scales inside or outside the tube. The cross-slide stage has a 1-in. movement in two horizontal directions at right angles by means of two screws with micrometer dials which read to 0.0001 in. A vertical rack and pinion between the microscope and column are used to focus the microscope on the work.

Courtesy Robbins Engineering Co.

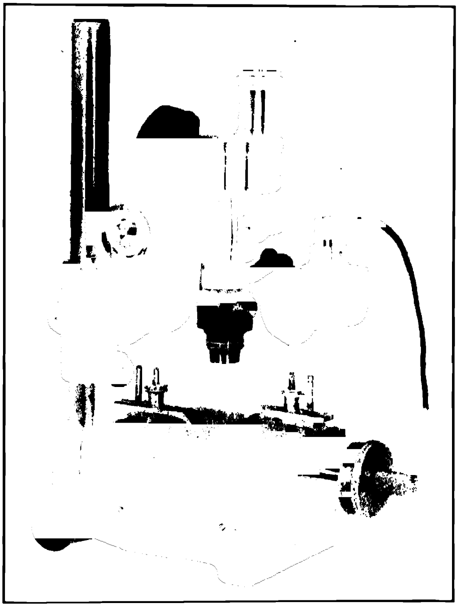
FIG. 16. A Compound Sine Plate with a Permanent Magnetic Chuck Set Up with Master Blocks to Facilitate the Surface Grinding of a Definite Compound Angle.

For transparent material or profile work, illumination is obtained by guiding a beam of light from the rear of the base by a train of mirrors, upward through the stage into the field of vision of the microscope. A quartz insert set flush with the upper surface of the stage protects the slides from dust and permits the light to travel through the stage. When opaque objects are measured, a vertical illuminator on the lower end of the tube with an auxiliary lamp may be used, as shown.

Any point, line, or edge of the work clamped to the stage and located directly under the cross line seen in the microscope is accurately located by the micrometer dials. By moving the stage to bring a second point or line into position, new measurements are obtained.

Actual distances between any two points are determined in this way.

The Toolmaker's microscope may be used for a great variety of work when provided with attachments, such as illuminators, special eyepieces, screw-thread diameter-measuring attachment, and lead and screw-thread measuring attachment with V grooves and accurate centers. In measuring the lead of a thread, the tap, bolt, hob, or threaded part is placed between centers. One cross line of the eyepiece is brought in line with the edge of one tooth. A micrometer reading is made. The adjacent tooth is next located under the cross line and a second reading taken from which the thread pitch is determined.



Courtesy Bausch and Lomb Optical Co.

FIG. 17. A Toolmaker's Microscope with Regular Eyepiece Giving a Magnification of 42×, Auxiliary Illuminator, Compound Cross-Slide Stage, and Object Clamps.

Where extreme accuracy in linear measurement is required, master gage blocks may be inserted between two holders shown in the foreground. One shoulder-type holder is attached to the base, and its mate, an overhung holder, to the slide immediately above. With blocks of a given thickness between the holders, the table is moved against the blocks by the micrometer screw. This definitely locates the work on the table for those blocks. A second pair of block holders is located on the rear side of the stage to measure the relative position of the upper slide to the lower. By substituting different stacks of blocks in these two holders, exact measurements of the work on the stage can be made.

Compound tables of this general type using master gage blocks for accurately locating machined surfaces are employed on jig borers, boring mills, drill presses, etc.

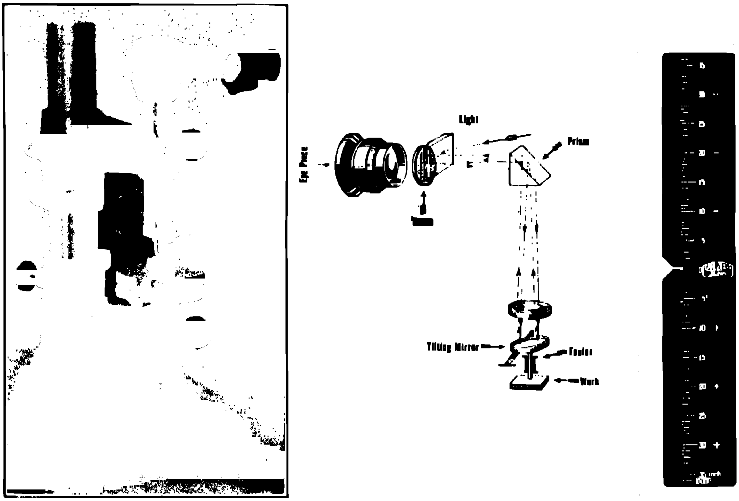


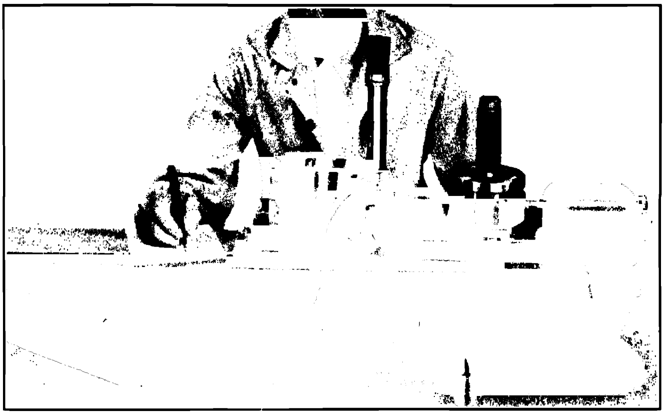
Fig. 18. The Carl Zeiss Optimeter.

With a diagram of the optical system and a view of the stationary index and scale in the field of observation. Readings are made directly to 0.00005 in.

The **binocular microscope** enables the observer to obtain a stereoscopic view of a surface, cutting edge of a tool, the grain of fractured metal, etc.

An **optical comparator** or Optimeter is a gage used for comparing the size of various parts with that of master gages as illustrated in Fig. 18. The operating mechanism comprises a mirror which is tilted by the action of a feeler-point bearing against the work and a graduated scale on the lens in front of the eyepiece. By the aid of prisms and lenses, the scale is projected upon the mirror and reflected into the eyepiece. By use of master gage blocks, the instrument is set so that the scale in the eyepiece rests at zero, as shown. With the work to be inspected substituted for the gage blocks, the feeler point is raised or lowered. The amount of deviation from the set position is plainly indicated by the travel of the scale.

The optical tube and its supporting bracket are both vertically adjustable on the column. Close adjustment for setting the scale with gage blocks is obtained by raising and lowering the table by a fine-pitch screw and knurled nut just below the table. The table is hardened and lapped to an optical finish, and thus forms a practically perfect plane. It is adjusted for parallelism by means of three screws in a fixed plate just below the table. The feeler point resting against the work may be raised slightly by means of a small lever while placing and removing the work. The pressure exerted by the feeler point on the work is very small and is kept uniform by the action of a small spring.



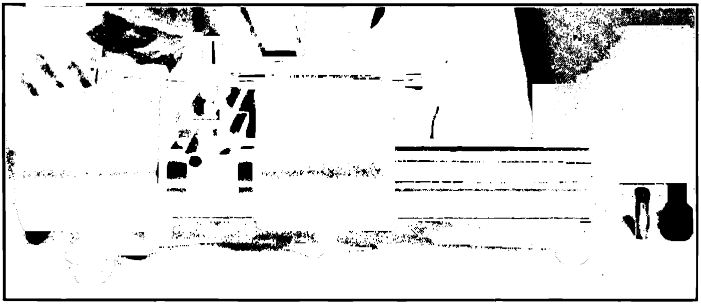
Courtesy Pratt and Whitney (Division Niles-Bement-Pond).

FIG. 19. A Rear View of the Linear Measuring Machine Set Up for Measuring the Pitch Diameter of a Thread Plug Gage by the Three-Wire Method.

The tailstock has the electrolimit constant-pressure spindle with the indicator mounted on the head.

Optimeters of this type may be fitted with a number of standard and extra attachments to make them adaptable to a wide range of work.

Measuring machines are designed for very accurate internal and external measurements, both absolute and comparative. These machines must be rigid and accurately constructed and have a means of obtaining a light and constant pressure on the work. **Mechanical measuring machines** usually have accurate linear scales on the edge of the bed to even units of length, but are provided with accurate lead screws and large graduated dials for measuring subdivisions. The Pratt and Whitney **standard measuring machine,** Fig. 19, consists of a heavy cast-iron bed provided with ways upon which two heads are mounted. One head, the footstock, is normally fixed to the bed. The headstock is located along the bed, over fine lines spaced exactly 1 in. apart on a master bar along the rear side of the bed, by means of a microscope. A precision screw is provided in the sliding head to determine the fractional parts of the inch. It has 25 threads per in. to give a lead of 0.040 ipr. The index wheel has 400 graduations, each graduation representing 0.0001 in. A Vernier with a magnifying glass subdivides these graduations into 10 parts so that final readings directly to 0.00001 in. may be made. In order to obtain and repeat accurate readings, the pressure of the measuring anvil against the specimen is carefully controlled at 2½ lb for general work or at 1 lb for delicate work. Temperatures should be held at 68° F.



Courtesy Pratt and Whitney (Division Niles-Bement-Pond).

FIG. 20. Pratt and Whitney Supermicrometer with Constant-Pressure Tailstock of 1 or 2½ lb with a Micrometer Head Measuring to 0.0001 in.

The setup is for measuring *M*, the distance over three wires, for determining the pitch diameter of a thread plug gage.

The **Supermicrometer**, Fig. 20, is substantially a heavy, rigid measuring machine based on the principle of a micrometer. The bed is not graduated for locating the tailstock but rather the 8-in.-capacity instrument is equipped with 8 accurate cylindrical disks each 1.0000-in. diam. which, supported on a channel bar extending through the tailstock to the headstock, supports the number of standard disks so that with the micrometer set on 0 and the proper number of disks between the headstock and the anvil, the tailstock is clamped to the bed when the pressure indicator is on 0. The final adjustment is made by moving the Vernier adjacent to the micrometer drum. The micrometer spindle in the headstock does not rotate but is graduated in half-tenths inches (0.050 in.) read in relation to an index line on the head. The large micrometer drum contains 50 divisions, each one of which represents a spindle travel of 0.001 in. It is turned by means of the knurled end.

The scale is read in relation to the adjacent Vernier to give readings of 0.0001 in.

The Van Keuren **light-wave micrometer** measuring machine, Fig. 21, provides a means for taking readings under any desired pressure between the work and spindle. The number of light bands shown on the steel flat indicates the deflection of the C frame of the machine and therefore the pressure. One or two ounces is recommended for measuring rubber, 1 lb for gages and precision parts and for screw threads of 22 pitch and finer, and 2½ lb for the coarser threads. The ball tester is used for testing parallelism between the anvil and spindle. Thread **best wires** are measured over a 0.750-in.-diam. roll or by crossing one wire over the other two. The steel flat is chromium plated and a red selenium glass screen is arranged so that light interference bands are formed on the steel flat according to the deflection of the glass optical flat above. The 6-in.-diam. wheel carried on a ½-in.-diam. screw with 40 threads per inch has 0.0001-in. graduations $\frac{1}{10}$ in. apart to give readings to 0.00001 in.

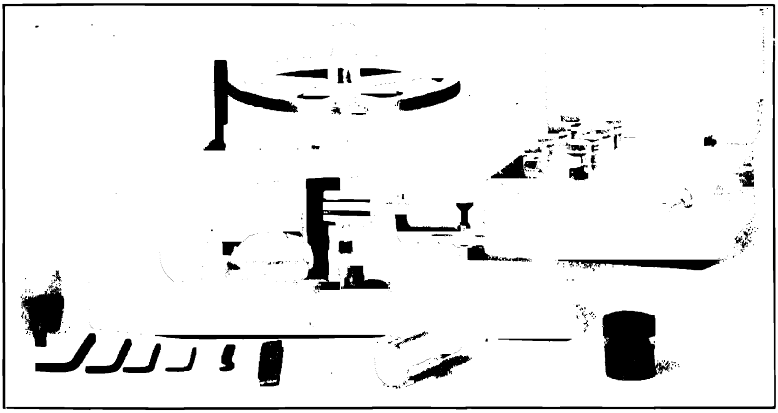


FIG. 21. The 0–2-in. Van Keuren Light-Wave Micrometer with Balancing Stand Accessories and a Box of Standard Rolls.

The pressure on the work can be varied from 0 to 2½ lb for each reading as indicated by the number of light-wave bands shown on the steel flat below the glass. Normally 2 or 3 light-wave bands on the steel flat indicate satisfactory working pressure. One band corresponds to 6-oz pressure, two bands to 12-oz, 3 bands to 18-oz, etc. A separate calibration accompanies each instrument.

The use of the principle of **light-wave interference** makes it possible to measure to a high degree of precision. Surfaces may be tested for flatness by using an **optical flat** through which monochromatic light of known wave length is directed. An optical flat is a plano lens of glass with one side very accurately flat. The other side is usually flat, but the two are not necessarily parallel. Both sides are polished and clear. When the accurate face is placed on another highly polished surface, light is reflected from the two surfaces in contact. The two surfaces are separated by a thin wedge of air. The light waves reflected from one surface may be in step or out of step with those reflected from the other across the wedge. When they are out of step, the light waves interfere, as evidenced by the presence of dark bands. With an air wedge between an optical flat and any other flat surface, alternate bands of light and dark appear at right angles to the direction of the wedge, as shown in Fig. 22. If the bands are straight and parallel, as shown, the surface being inspected is truly flat. If the bands are curved, the amount of curvature gives the measure of the variation from true flatness. When the test surfaces are not flat, the light and dark bands produce the effect of a contour map.

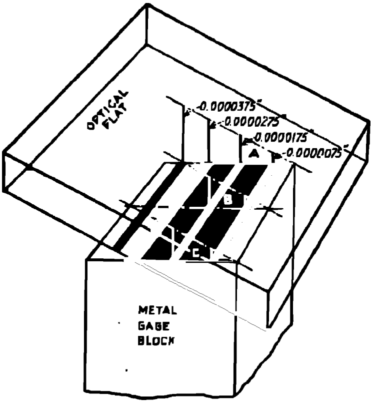


FIG. 22. An Exaggerated Condition of an Optical Flat Making an Angular Contact with the Upper Face of a Flat Gage Block.

When light traveling in air is reflected at a quartz or glass surface there is a change in phase of π radians (see Wood, *Physical Optics*). When light traveling in a denser medium, such as glass, is reflected at the surface of a less dense medium, such as air, no change in phase occurs. For this reason, an interference band occurs at the line of contact between two plane glass or quartz plates forming a slight wedge between them. The first dark band to the left occurs where the plate separation is ½ wave length, $\gamma/2$, the second at γ, etc., giving vertical steps of 10 millionths inch each, as shown in Fig. 22. When light is reflected from a metallic surface, the phase change is not π radians, but some other quantity depending on the metal, surface finish, and length of light wave. For the usual precision gage block, this additional phase loss amounts to about 2.5 millionths inch. Therefore, no dark band appears at the line of contact, but at a distance from the edge of ¾ of the space between succeeding bands. When using white light, this vertical distance is equivalent to 7.5 millionths inch. The second dark band to the left occurs at an additional vertical distance of ½ γ (10 millionths inch), making a total of 17.5 millionths inch, etc.

Light-wave lengths are definite quantities which have been determined accurately and which can be duplicated at any time and anywhere. The length of a light wave depends upon the color of the light. White light such as that from the sky or from an electric light bulb has a wave length of approximately 20 millionths inch. White light contains all colors and, therefore, is not wholly satisfactory for light interference work, as the bands are not sufficiently definite. Monochromatic light, obtained through a red selenium glass generally used, eliminates all colors except red, to give a wave length of 25 millionths inch.[13] A yellow helium monochromatic light having a wave length of 23.2 millionths of an inch is also used.

Light-wave interference produced by the optical flat also may be used to compare the size of an unknown block with that of one of known size. Two optical flats or one optical flat and a Toolmaker's steel flat and a known standard gage are required. The block to be measured and the standard are carefully wrung onto the face of the steel flat. The optical flat is then placed over the two blocks. If the bands on one block are a continuation of the ones on the other, the blocks are identical. If not, the displacement of the bands is an indication of their difference.

Figure 23, left, shows how the size of two steel balls is compared with a master gage block 11/16 in. diam. and 0.250 in. thick. A cardboard templet, as shown in the line diagram, serves to locate the balls at a definite distance equal to the diameter of the gage from the master gage block. The point of contact between the upper optical flat and the master gage block determines whether the balls are large or small. If the contact is on the outer or left edge of the block, the balls are oversize, and vice versa. The thickness of the air wedge between the upper optical flat and the gage block at their point of contact is equal to zero. The wedge increases in thickness from this point of contact by 10 millionths inch for every band. Fourteen dark bands may be counted on the face of the block, which would give a total of 28 bands in the 1⅜ in. from the left edge of the block to the center line of the balls, indicating the balls to be oversize 28 times 10 millionths or 0.00028 in. The fact that the light bands are practically parallel to the center lines of the balls indicates that the two balls are of the same size. Figure 23, center, shows in elevation and plan view the setup for measuring two balls (or cylinder) when using a ¼-in.-thick gage block. The light bands appearing on the face of the block at an angle, as shown at the right, indicate that one ball is smaller in diameter than the other. If a cylindrical plug were being measured instead of the balls, the picture would indicate one end of the plug to be smaller than the other. The exact size of the balls or the cylindrical plug could be determined by continuing the dark bands until they intersect the axis of the cylinder or of the two balls. That band through the point of contact on the block extended to the center line of the work indicates the point of exact size of the work. The intersection of other bands similarly shows the size of the work at other points along the axis.

The interferometer: The Michelson interferometer or absolute interference comparator is used for measuring short lengths. It usually employs the rays from sodium light, having a wave length of 0.00002 in. These light waves fall at 45 deg on a plane-parallel glass plate, the surface of which is covered with a semitransparent film of silver or platinum. Light of equal intensity is reflected and transmitted to equidistant mirrors facing the central glass plate but placed 90 deg apart. The light is reflected from the two mirrors to the central lens and thence to a screen or microscope. Bands pass the cross hair in the telescope as one of the mirrors is slowly displaced the small distance to be measured, such as the thickness of a block. The observer counts them as they pass.

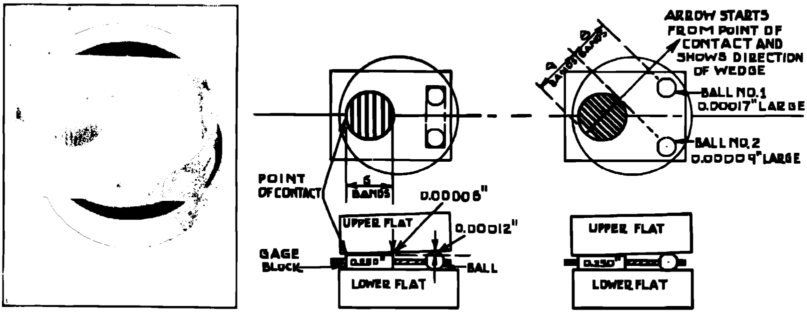


FIG. 23. Two Optical Flats Used to Compare the Size of Two Balls with That of a Master Gage Block.

Knowing the length of a part to within one-half wave length, it is possible to determine its length to an accuracy of one-tenth of this amount by using successively the spectrum colors of red, yellow, green, blue-green, blue, and violet from helium light in the interferometer comparator. These light waves have definite relations with one another at various distances from the source. Constellations of fractional divisions recur at uniform intervals. Since the recurrence of constellations is absolutely known, lengths may be determined to a very high degree of accuracy.

GAGES

Definition

Gaging is a process of measuring to assure a specified uniformity of size or contour. An unknown is usually compared with a known standard. A gage is a device for determining whether or not one or more of the dimensions of a manufactured part is within specified limits. The term gage is used freely for special measuring devices, and the division line between measuring instruments and gages is often obscure. The advantages of a gage are the speed with which it may be used, the accuracy obtainable, and the extent to which it is foolproof.

Classification of Gages

Gages may be classified in several ways as follows:

1. According to accuracy, purpose, or use, as:
   (*a*) Shop or working gages.
   (*b*) Inspection gages.
   (*c*) Reference or master gages.
2. Internal or external.
3. Allowance for tolerances, as:
   (*a*) Nonlimit or one size.
   (*b*) Limit or two size.
4. According to shape or form, as:
   (*a*) Plug.
   (*b*) Ring.
   (*c*) Receiving.
   (*d*) Caliper.
   (*e*) Snap.
   (*f*) Special form, profile, such as radius, thread, gear tooth.
5. Indicating type.
6. Functional.

Working, Inspection, and Master Gages

Shop or working gages are used by machine operator or shop inspector to check the work as it is produced. Working gages have limits within those of the piece being inspected.

An **inspection gage** is one used by the manufacturer or purchaser in accepting the product. These gages must not reject any product which working gages will accept. They should, therefore, be more accurate than working gages. Inspection gages are used also by inspectors to check the finished pieces turned out by the operators, and in that way serve as a check on the inspection of the workman and the working gages.

A **master gage** is one in which gaging dimensions represent as exactly as possible the physical dimensions of the component. It is the gage with which all other gages and all dimensions of manufactured material are finally checked, directly or by comparison. Gages of this type are the Hoke, Johansson, and Van Keuren, as described above under *Master Gage Blocks*. Reference blocks, disks, or rods, or master plug and ring gages are made frequently to accurate size for use as measurers or for checking micrometer calipers, inspection gages, and other measuring instruments and gages.

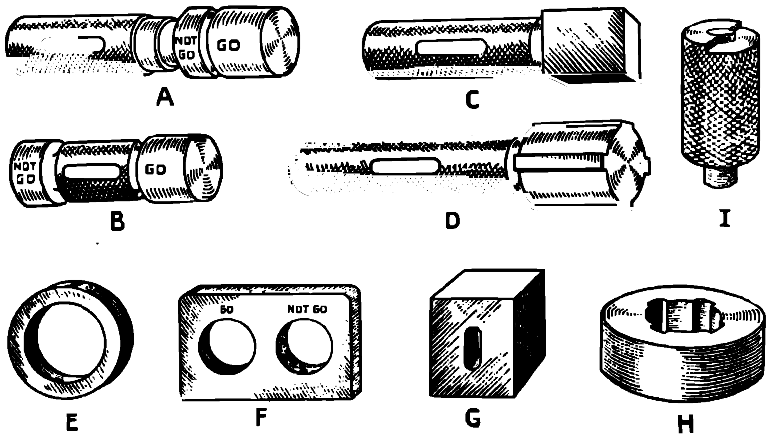


FIG. 24. Plug, Ring, and Receiving Gages.

Several forms of plug gages, showing the " limit " cylindrical plug at *A* and *B*, the square plug at *C*, and the spline plug at *D*. A ring gage is shown at *E*, a " limit " ring gage at *F*, receiving gages at *G* and *H*, and a limit ring gage for tapers at *I*.

Limit Gages

Gages which allow for a tolerance are called limit gages. They are usually referred to as *go* and *not go* gages. The **limit plug gage** at *A*, Fig. 24, has cylindrical plugs of two diameters. The first should *go* into the hole, the second plug should *not go*. At *B* is shown a *go* and *not go* circular plug gage with a *go* plug on one end and a *not go* plug on the other.

A **limit ring gage** is shown at *F*. The shaft being tested should be small enough to go into the *go* hole, but too large to go into the *not go* hole. A **limit ring taper gage** of the feeler type, at *I*, is commonly used for testing tapers as to diameter and taper. If it fits snugly, the taper is correct; if the end of the bar being tested passes the lower shoulder but does not pass the upper shoulder, it is of correct diameter.

In limit snap gages, Fig. 26, the work should pass the first space, but should not go past the second. The value of the limits is stamped on each *go* and *not go* gage.

Shape and Form Gages

A plug gage is one in which the outside measuring surface is arranged to verify the specified uniformity of holes. A plug gage may be cylindrical or of any cross-sectional shape, as shown at *A* to *D* in Fig. 24, or tapered as at *I*. The wearing surface of the gage may be made either integral or replaceable with the handle. It may be solid or adjustable.

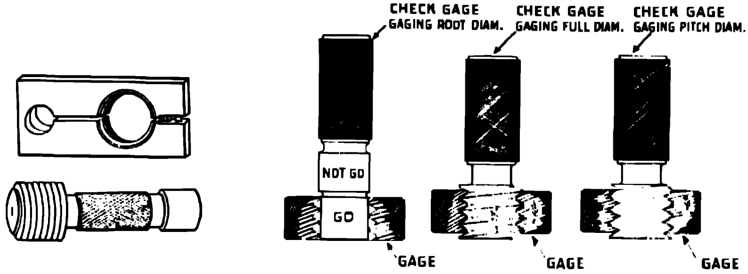


FIG. 25. Plug and Ring Thread Gages.

Plug and adjustable ring thread gages are shown on the left. Plug gages for checking female thread gages in three steps are shown on the right.

Thread plug gages are form gages for testing threaded holes. A mating plug and ring gage for checking threads is shown on the left in Fig. 25. The cylindrical end of the plug gage has a diameter equal to the **minor** diameter of the threaded hole. The **threaded ring gage** is adjustable by means of a screw passing across the gap at the right end so that various sizes may be obtained. A set of three plug gages for checking thread gages is shown on the right in Fig. 25. The limit plug gage checks the minor diameter, the second thread gage checks the major diameter, while the third gage checks the pitch diameter. The gaging or measuring of threads is discussed further in connection with Fig. 35.

A ring gage has an inside measuring surface circular in form as at *E* and *F* in Fig. 24.

A snap gage, sometimes referred to as a **caliper gage,** Fig. 26, is arranged with inside measuring surfaces for calipering diameters, lengths, or thicknesses. Snap gages may be solid, adjustable, or built up. A solid C-type snap gage having a flat lower jaw but stepped upper jaws is shown at *A*. The outer step of the upper jaw serves as the *go* gage; the inner step, slightly closer to the lower jaw, serves as the *not go* gage. In the solid I-type snap gage, shown *at B*, one side serves as a *go* gage and the other as the *not go*. The snap gage at *C* has a fixed wear-resisting solid anvil at the top, but two adjustable anvils at the bottom, which are set to desired limits with master gage blocks to form *go* and *not go* gages. Limit snap gages with two sets of adjustable anvils are shown at *D* and *E* in Fig. 26. The adjustable anvils are locked and sealed in position. Heat-insulating pads may be attached to the frame to prevent distortion caused by heat from the hand. The anvils are sometimes formed for specific work, as to the shape of screw threads at *F*, Fig. 26. With the limit caliper thread gage supported in a stand, threaded parts may be held in both hands and passed between the anvils as a means of rapid checking of pitch diameter and thread angle. Straight or roll multiple-thread limit snap gages are used extensively in interchangeable manufacture to disclose errors in diameter, straightness, roundness, lead, angle, and thread profile.

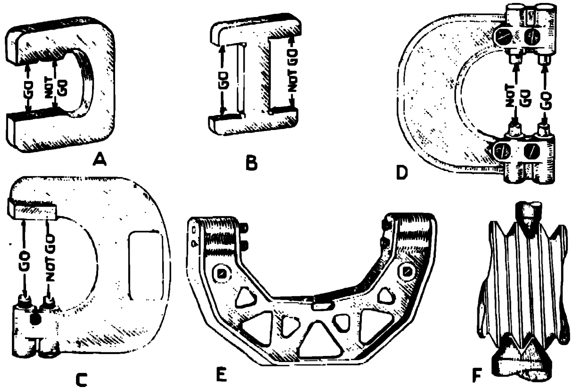


FIG. 26. Solid and Adjustable " Limit " Snap Gages.

Special **form gages** are those made to correspond with a definite form. Gages of this type are made for a wide variety of purposes, such as the radius gage in Fig. 27, and the screw-thread pitch gage in Fig. 28.

A **plate-snap gage** made from sheet steel for checking all dimensions on a small screw is shown in Fig. 29*A*. A *go* and *not go* gage is provided for each dimension.

A **flush pin gage,** Fig. 29*B*, represents a type of gage used to determine the tolerances on surfaces of different heights. It is a limit type of gage and very generally used. Figure 29C, at the right, shows a plate gage also used for gaging the height of shoulders, etc.

Gage Design

Tolerances on working and inspection metal gages must be in accordance with the requirements. In general, the smaller the tolerance, the more the gage will cost and the shorter its wearing life will be. If the part to be inspected has a wide tolerance, it is economical to specify a more reasonable tolerance on the gage.

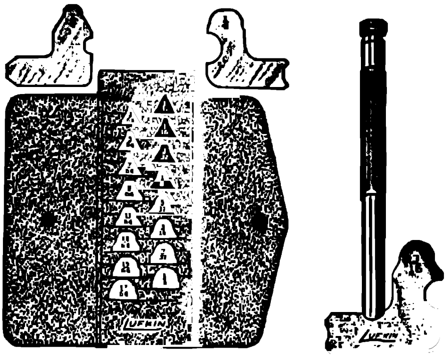


FIG. 27. Radius Gages of the Unit Type with Internal and External Forms.

The gage may be clamped on the holding rod at any convenient angle.

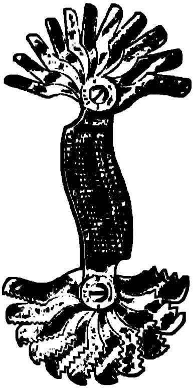


FIG. 28. A Screw Thread Gage for Roughly Indicating the Pitch or Number of Threads per Inch of Inside or Outside Threads, Containing 24 Gages of Pitches from 36 to 4.

The majority of gages are made to a common standard in which the gagemakers' limits of accuracy do not exceed 10 per cent of the size difference between the *go* and *not go* gaging members. Exceptions to the rule may be made when smaller tolerances are applied, when comparators, such as an air gage or amplifying gage reading to greater accuracy, may be used, and when the 20 per cent and 10 per cent rule or the Army Ordnance system is used. In all cases the gage tolerance is always in the range covered by the product tolerance so that the *go* plug tolerance would be plus and the *not go* plug tolerance would be minus. The Unilateral system of tolerances is applied, except on master setting disks where Bilateral tolerances are used, the total of which equals the normal Unilateral value.

Table 1 gives the gagemakers' tolerances which are applied unilaterally for several classes of precision gages. These tolerances vary with the nominal size of the gage. For example, if a hole to be gaged has a 1.000 in. basic size and a plus tolerance of 0.002 in. to

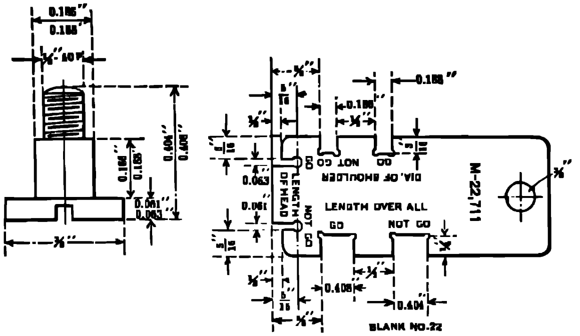
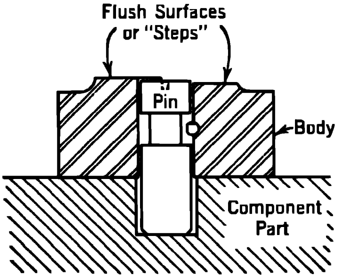
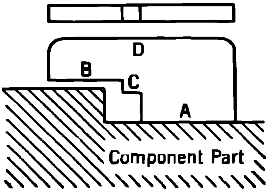


FIG. 29A. A Profile Gage for Gaging All Dimensions of the Screw Shown at the Left.



B



C

FIG. 29B. A Flush Pin Gage, Shown Gaging the Depth of a Hole.

In the position shown, the top of the pin stands between the " two steps " (depth tolerance) on the body surface when the lower end touches the bottom of the hole. The depth of the hole is shown to be within tolerance.

FIG. 29C. A Limit Plate Gage Shown Applied in Gaging the Height of a Shoulder.

The surface *A* rests on the lower plane of the part in such a way that the surface *B* should go over the shoulder, whereas the surface *C* of the gage should not pass over. The tolerance on the height of the shoulder is represented by the distance *BC*.

give gaging limits of 1.000–1.002 in. and if an X class of gage is desired, the *go* plug would have limits of 1.0000–1.00006 in. The *not go* gage would have limits of 1.0020–1.00194 in. No allowance is made for wear. The above tolerances merely cover the tolerances required by the gagemakers. If working and inspection gages are needed, the working gages could be made to larger tolerances, such as Class Z, and the inspection gages made to the smaller tolerances, such as Class X or Y. In some cases, however, two sets of gages of the same class are ordered, and those gages measuring nearest to the basic size would be used as inspection gages.

TABLE 1. THE INDUSTRIAL STANDARD FOR UNILATERAL TOLERANCES FOR PLUG, RING, CALIPER, AND FLUSH PIN GAGES

Nominal Size of Gage, inches		Gagemakers' Tolerances, classes				
Above	To and Including	XX (Male Gages Only)	X	Y	Z	ZZ (Ring Gages Only)
0.029	0.825	0.00002	0.00004	0.00007	0.00010	0.00020
0.825	1.510	0.00003	0.00006	0.00009	0.00012	0.00024
1.510	2.510	0.00004	0.00008	0.00012	0.00016	0.00032
2.510	4.510	0.00005	0.00010	0.00015	0.00020	0.00040
4.510	6.510	0.000065	0.00013	0.00019	0.00025	0.00050
6.510	9.010	0.00008	0.00016	0.00024	0.00032	0.00064
9.010	12.010	0.00010	0.00020	0.00030	0.00040	0.00080

Many use 20 per cent of the tolerance on the component part for work gages and 10 per cent for inspection gages. In each case, one-half of the amount is used for wear on the *go* gage and one-half for gagemaker's tolerance on both the *go* and *not go*, as illustrated in Fig. 30. The *go* plug must enter the smallest hole. The plus-wear allowance and tolerance increase the plug size over the basic hole

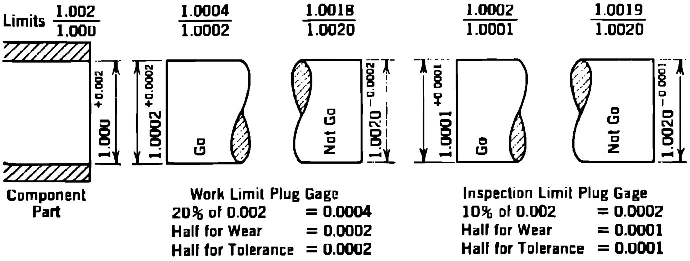


FIG. 30. The Tolerances and Limits of Work and Inspection Limit Plug Gages for the Component Part Having a Bore of 1-in. Basic Size and a Tolerance of Plus 0.002 in. Are Shown.

size. The *not go* plug should not enter the largest hole. No wear is allowed in this case, and the tolerance is negative.

The tolerance on the snap gage should be minus on the *go* and plus on the *not go* gages. Allowance for wear is made only on the *go* gage. The *go* gage of plug, ring, and snap gages is the one most often replaced because of wear.

The U. S. Army Ordnance has developed a system of gage tolerances to provide both gagemakers' tolerances and wear on the *go* gages. It is similar to the 20 and 10 per cent rules except that values of tolerances and wear for each value of component tolerance, rather than for the nominal size, have been tabulated. Its purpose is to eliminate some interference obtained by the straight 20 and 10 per cent rule. This system is used in the design of plain plug, plain ring, flush pin, and adjustable snap gages.

For example, the inspection plug gage is designed from values in Table 2. For a component tolerance of 0.002 in., a 1-in.-diam. *go* inspection gage will have limits of 1.0001–1.0002 while the *not go* inspection gage will have limits of 1.002–1.0019 in. The working gage is designed from values given in Table 3. The 1-in.-diam. *go* working plug gage will have limits of 1.0005–1.0006 in., and the *not go* gage will be from 1.0019–1.0018 in. It is seen that work accepted by the working gages cannot be rejected by the inspection gages.

Materials and construction of gages: Precision gages and measuring instruments should be made of materials which are stable and wear resisting. Snap gages are made of steel plate and sheet, steel forgings, cast iron, or malleable cast iron. When rapid wear is to be avoided, the **working surfaces** are made of pack-hardened low-carbon steel, tool steel, or other alloy steels which, after being hardened, are ground and carefully lapped. Stellite often is used for the working surfaces of gages. Chromium-plated steel is used extensively in large-production shops as the chromium is extremely hard and wear resisting. After wearing, it can be built up by replating. The practice of making the working surfaces of nitrided steel or tipping them with sintered carbide is increasing. The contact points of many gages and work-sizing devices are made up of highly wear-resistant materials such as sintered carbide, sapphire, boron carbide, or diamonds. Often the working parts of a gage, such as the cylindrical plugs on a plug gage, are attached to an aluminum, plastic, or low-carbon-steel handle. Expensive material is saved and the working parts are replaceable or sizes are interchangeable.[16] During World War II glass plug and ring gages were used extensively because of the shortage of other wear-resisting metals. The glass gives fairly good wearing life, has

TABLE 2. INSPECTION GAGES

Wear allowances and gagemakers' tolerances for plain plug and ring inspection gages, including plain ring gages for major diam. of screws, and plain plug gages for minor diam. of nuts.*

		Go		*Not Go*	
Gage Type	Comp. Tol.	Gage Wear	Gage Tol.	Gage Wear	Gage Tol.
Plug ring, and fixed snap gages	0.0005	0.0000	0.00005	0	0.00005
	0.001	0.0001	0.0001		0.00005
	0.002	0.0001	0.0001		0.0001
	0.003	0.0001	0.0002		0.0001
	0.004	0.0002	0.0002		0.0002
	0.005	0.0003	0.0002		0.0002
	0.006	0.0004	0.0002		0.0002
	0.007	0.0004	0.0003		0.0002
	0.008	0.0005	0.0003		0.0002
	0.009	0.0005	0.0004		0.0002
	0.010	0.0005	0.0005		0.0003
	0.012	0.0006	0.0006		0.0003
	0.014	0.0006	0.0008		0.0004
	0.015	0.0006	0.0009		0.0005
	0.016	0.0006	0.0010		0.0005
	0.018	0.0006	0.0010		0.0006
	0.020	0.0006	0.0010		0.0007
Flush pin and adjustable snap gages	0.0005	0	0.00005	0	0.00005
	0.001		0.00005		0.00005
	0.002		0.0001		0.0001
	0.003		0.0001		0.0001
	0.004		0.0002		0.0002
	0.010		0.0003		0.0003
	0.015		0.0004		0.0004
	0.020 & Up		0.0005		0.0005

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* By J. B. Nealey.

Procedure for Determining Gage Dimensions

Plug	*Go:* To min. limit add gage wear, apply tolerance plus. *Not Go:* From max. limit, no gage wear, apply tolerance minus.
Snap and Ring	*Go:* From max. limit subtract gage wear, apply tolerance minus. *Not Go:* To min. limit, no gage wear, apply tolerance plus.

Size to be Marked on the Gage

Plug	*Go:* Min. limit of component. *Not Go:* Max. limit of component.
Snap and Ring	*Go:* Max. limit of component. *Not Go:* Min. limit of component.

TABLE 3. WORKING GAGES

Wear allowance and tolerance of working gages based on value of component tolerance*

Gage Type	Comp. Tol.	*Go*			*Not Go*		
		Gage Wear	Gage Tol.	△G†	Gage Wear	Gage Tol.	△N†
Plug, ring, and fixed snap gages	0.0005	0.00015	0.00005	0.00005	0	0.00005	0.00005
	0.001	0.0003	0.0001	0.0002		0.00005	0.00005
	0.002	0.0003	0.0001	0.0002		0.0001	0.0001
	0.003	0.0004	0.0002	0.0003		0.0001	0.0001
	0.004	0.0006	0.0002	0.0004		0.0001	0.0002
	0.005	0.0007	0.0002	0.0005		0.0002	0.0002
	0.006	0.0008	0.0002	0.0006		0.0002	0.0002
	0.007	0.0009	0.0002	0.0007		0.0002	0.0002
	0.008	0.0010	0.0002	0.0008		0.0002	0.0002
	0.009	0.0011	0.0003	0.0009		0.0002	0.0002
	0.010	0.0012	0.0004	0.0010		0.0002	0.0003
	0.012	0.0015	0.0005	0.0012		0.0003	0.0003
	0.014	0.0017	0.0006	0.0014		0.0003	0.0004
	0.015	0.0018	0.0007	0.0015		0.0004	0.0005
	0.016	0.0020	0.0008	0.0016		0.0004	0.0005
	0.018	0.0020	0.0009	0.0016		0.0005	0.0006
	0.020	0.0020	0.0010	0.0016		0.0006	0.0007

Procedure for Determining Gage Dimensions

Plug
Go: To min. limit add △G and gage wear, then apply tolerance plus.
Not Go: From max. limit subtract △N, no gage wear, apply tolerance minus.

Snap and ring
Go: From max. limit subtract △G, subtract gage wear, apply tolerance minus.
Not Go: To min. limit add △N, no gage wear, apply tolerance plus.

Size to Be Marked on the Gage

Plug
Go: To min. limit add △G.
Not Go: From max. limit subtract △N.

Snap and ring
Go: From max. limit subtract △G.
Not Go: To min. limit add △N.

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* By J. B. Nealey.

† △G equals gage wear plus tolerance of "go" *inspection* gage.
△N equals tolerance of "not go" *inspection* gage.

practically a zero thermal coefficient of expansion, and when scratched merely chips rather than leaving burrs on the surface as do most metals.

Indicating Gages

An indicating gage is one that registers the size of the part on some form of indicator. Various forms of indicators are in use, such as the feeler-type ring gage, Fig. 24*l*, and the beam, amplifying, dial, optical, fluid, and electric types discussed below.

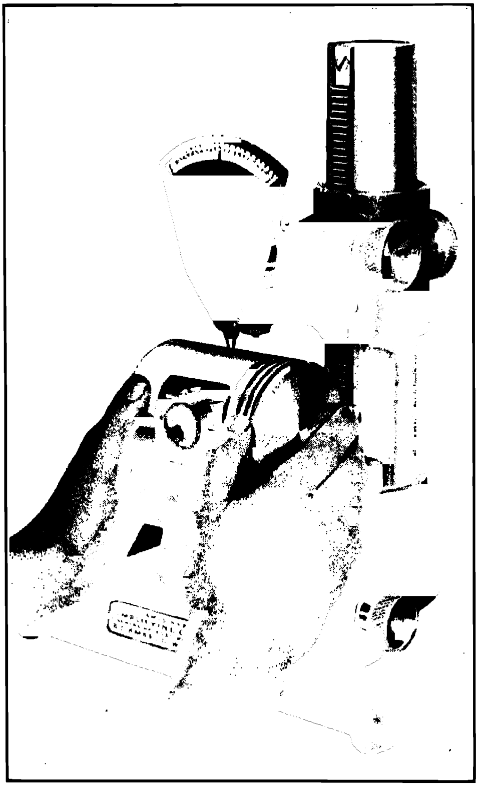
The beam type of indicating gage is shown in use with a surface gage in Fig. 15. The principal object of these indicators is to furnish a sensitive touch and register differences when comparing two nearly equal dimensions.

An **amplifying comparator** equipped with a diamond measuring point is shown in Fig. 31. This instrument is first set to the zero reading corresponding to the basic size of the work, with master gage blocks. Differences in size are registered directly on the scale to 0.0001 in., which is represented by a division of nearly $^{3}/_{16}$ in.

A **portable inside indicator gage**, Fig. 32, has one anvil of two fixed contact points. A movable anvil controls the indicator readings. The tool is located concentrically in the bore by the three anvils. Coarse and fine graduations to 0.001 in. and 0.0001 in., respectively, are read directly through the combined use of two pointers on the indicator.

The **star gage** was developed to gage the bores of guns and other long tubes. It consists of a tubular body of adjustable length. One end carries a head which holds three radial measuring rods, also adjustable in length. The rods are moved radially by a central wedge, the longitudinal movement of which is controlled from the handle. A standard ring is used to set the radial rods so the Vernier along the scale on the handle will read zero. As the gage is moved along within the bore to be measured, variations from the required diameter can be read at different distances from the end of the bore or at different angular positions for any depth.

Air gages are used for the rapid checking of the diameter, out-of-roundness, and taper of deep and shallow holes. They are accurate and fast. The device consists of an instrument containing a vertical slightly tapered glass tube. A small float in the tube rides the air which passes upward through the tube. Its vertical position is determined by the velocity of air. The plug is attached to the instrument directly or by a flexible tube. The plug has two holes in its cylindrical surface, diametrally opposite, through which air escapes. The plug is slightly smaller than the hole to be checked. The workpiece is acceptable if the float rides in the tube between two pointers, one of which is set at the position of the float when the plug is fitted into a part of maximum size permitted, and the other when fitted into a part of minimum size. Gages of maximum and minimum sizes are used to set and check the instrument.



Courtesy B. C. Ames Co.

FIG. 31. A Bench-Type Amplifying Gage.

After being set to zero and frequently checked with master gage blocks, this indicating gage is used for the routine inspection of aluminum-alloy pistons.

A Boroscope is an optical instrument with an eyepiece of 6× or 10× on one end, and a tilting mirror and light on the other which is extended into a bore so that the interior surface may be observed, to detect flaws and evaluate surface condition. The Precision Air Gage,

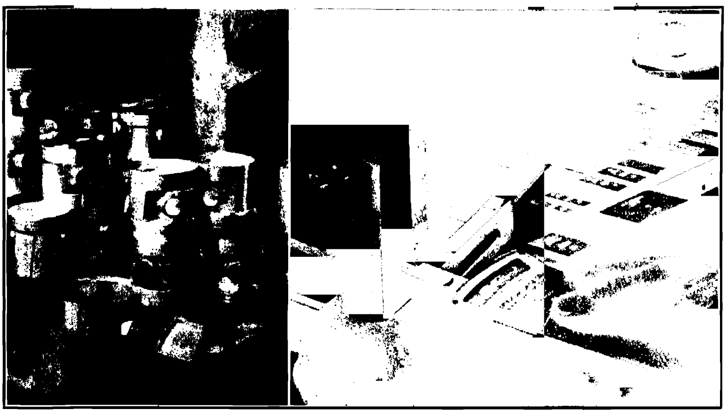


FIG. 32. A Swedish Gage Co. No. 2 Internal Indicator Being Set Up with Johansson Gage Blocks and Long Jaws Held in the Holder.

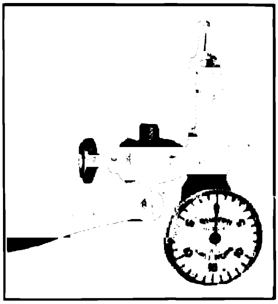
At the left, the indicator is being used to check the size of piston-pin holes to tolerances of plus or minus 0.00015 in. In mass production a master ring gage would be provided to set and frequently check the gage.

the Star Gage, and the Boroscope are all used on long bores or tubes, such as rifles, cannon, and hydraulic cylinders.

A **lathe-test indicator,** Fig. 33, held in the tool post with a contact ball against the revolving surface of the work, indicates eccentricity. The standard dial reads in 0.001 in. and has a range of 0.025 in.

A **quick-reading caliper gage,** Fig. 34, indicates the distance between the points directly on a dial gage. The points are first set to the required size by gage blocks and the gage adjusted to zero. Gages of this type are convenient for checking the diameters of work between centers in a lathe and grinder. **Dial gages** are constructed as self-contained units in a wide variety of types, dial sizes, markings, and stem strokes. They are built into many types of indicating gages.

An **indicating gage** used to compare the size of a screw thread as measured over three wires, with a stack of master gage blocks, is shown in Fig. 35. This is a convenient, rapid, and accurate method of checking screw threads. A **functional gage** determines the

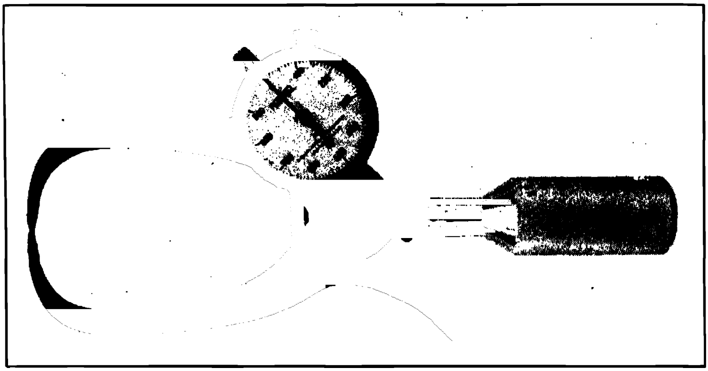


Courtesy L. S. Starrett Co.

FIG. 33. The "Last Word" Indicator Model *F*.

With full universal shank, swiveling tubular body, and detachable ratchet joint contact piece.

relation between two or more surfaces such as concentricity of a threaded hole and a counterbore.



Courtesy Federal Products Corp.

FIG. 34. A 3-in.-Range Direct-Reading Caliper Tool.

Readings to 0.001 in. are obtained along the chord.

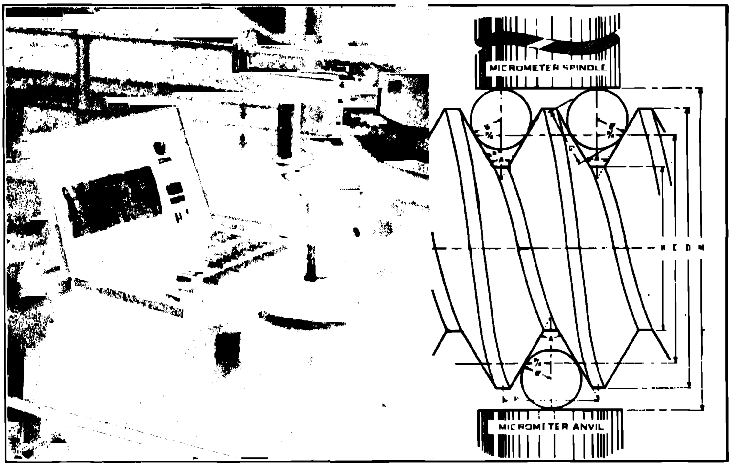


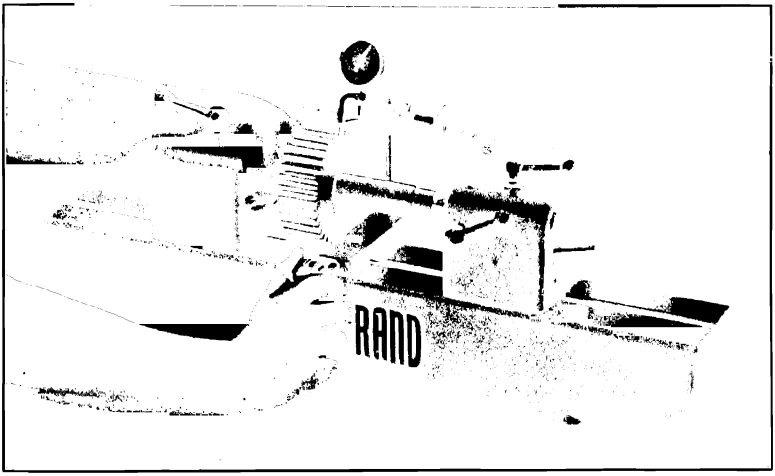
FIG. 35. An "American" Dial Indicator Amplifying Gage Used for Checking the Pitch Diameter of a Screw Thread by the Three-Wire Method.

The dial gage of the amplifier has been set to read zero for the computed measurement *M* by the stack of Johansson gage blocks shown on the surface plate. The dial gage shows plus or minus readings over the wires. The drawing by John Bath and Co. shows the relation of the three "best size" wires to the screw thread and gage spindle and anvil.

Bench centers, Fig. 36, are used for checking concentricity and run-out of parts mounted on centers. They are built to take work of various diameters and lengths. A dial test indicator attached to the bed is a standard part of the instrument.

Comparators

An inspection gage employing several dial gages is shown in Fig. 37. Many gages of this general character are used in the inspection of parts produced in large quantities.



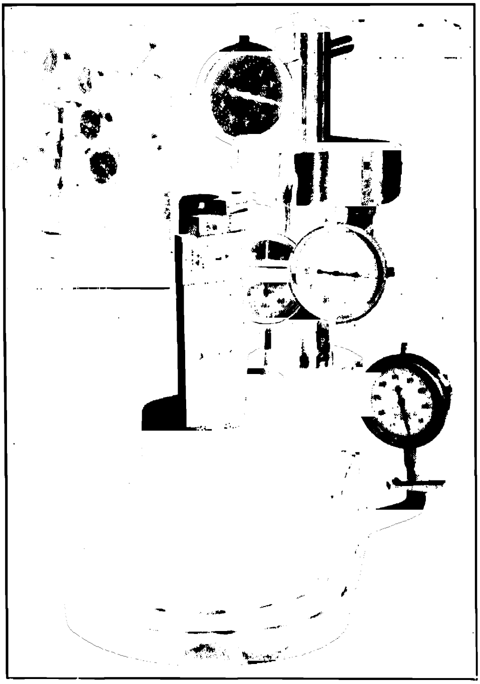
Courtesy Sundstrand Machine Tool Co.

FIG. 36. The Bench Center, Showing a Gear Mounted on a Mandrel Supported between Centers Being Checked for Wobble by a Dial Gage Supported on the Adjustable Carriage.

The **Electrolimit gage,** Fig. 38, combines mechanical gaging with electrical magnifications to check external or internal measurements. It can be set to any limits desired, ranging from ordinary shop thousandths to millionths of an inch. It consists essentially of a diamond contact point supported to move through a very limited distance. This unbalances a bridge circuit and causes the movement of the contact point to be magnified 500, 1,000, 10,000, or more times. This principle is applied in many ways. With rolls it gages continuously the thickness of sheet as it comes from the mill. The thickness of the sheet or strip is kept automatically within 0.0004 in.

The Sheffield Comparator is used for purposes similar to those of the Electrolimit and Zeiss Optimeter. Steel reeds magnify the deflection of the indicating pointer from the zero reading as set with master gage blocks with an amplification of 5,000 to 1 or more; a movement of the indicating point of 0.000025 in. appears on the illuminated dial as ⅛ in.

Special gages for checking gears and cutters are shown under *Gear Inspection,* and for automatically controlling the size of ground work under *Grinding Machines.*



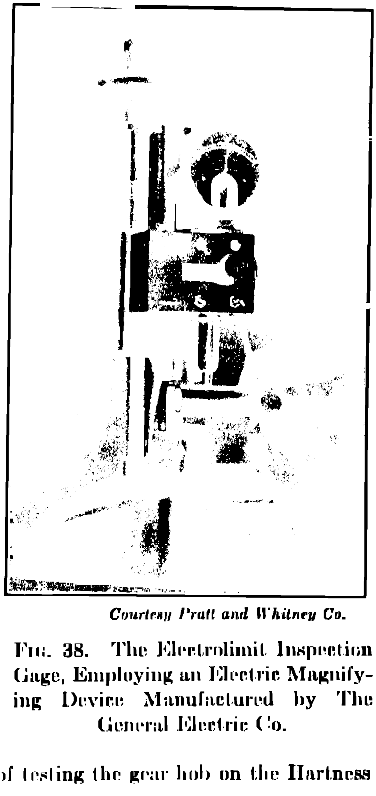
Courtesy Ford Motor Co.

FIG. 37. Special Indicator Gage Used for Routine Inspection of Transmission Gears.

The various dial gages are set to the correct zero reading by the use of Johansson master gage blocks, after which the part is inspected as shown in the insert.

Quality Control

Quality control is not merely inspection, nor is inspection alone any form of quality control. Inspection exposes deviations from specified quality standards, but it cannot prevent them. Quality control is actually a combination of actions or procedures which are intended to improve the quality of the product, as indicated by inspection records. Quality control may or may not indicate a change of tolerances. There can be no empirical rules of quality control which are applicable to all enterprises. Each must be determined by the demands of each particular industry. Quality control leads to (1) an improved product without increased cost, (2) reduction in cost of product without a lowering of quality, and (3) an increase in market demand for the product due to the attainment of objectives 1 and 2. The inspection of samples taken periodically at random indicates whether the product is conforming to specifications. If any single dimension, for example, is found changed, corrective measures may be instituted by regrinding or resetting tools, making machine adjustments, etc., to bring the work more closely in line with the expected quality.



Courtesy Pratt and Whitney Co.

FIG. 38. The Electrolimit Inspection Gage, Employing an Electric Magnifying Device Manufactured by The General Electric Co.

Inspection of Screw Threads

Screw threads are measured or compared in a number of different ways as follows:

1. By micrometer calipers or snap gages with shaped anvils, Fig. 26*F*.
2. By thread plug or ring gages, Fig. 25.
3. By comparing the superposed projected shadow with an accurate, greatly enlarged scale of a contour-measuring projector, Fig. 39*B*, similar to the method of testing the gear hob on the Hartness comparator, Fig. XIV-33.
4. By means of a toolmaker's microscope, Figs. 17 and 39*A*.
5. By the "three-wire" method, Fig. 35, using measuring instruments such as micrometers, measuring machines, and optical flats, or with comparators, as shown in Fig. 35.

In roughly checking one 60-deg-angle screw thread or tap with another, the micrometer caliper measurements over three wires on one screw should equal that of the other. For this purpose, the wires, often in the form of standard wire drills, should have a diameter not less than 0.50518*P* nor over 1.01036*P*, in which *P* is the pitch of the thread. When accurate measurements of the pitch diameter of a screw thread are desired, measurements *M* may be made over three wires, as shown in Fig. 35. The general formula for any diameter of wire G in inches, any half thread angle $\alpha = A/2$, and thread helix angle S is:

$$M - E = 2\left[\frac{G}{2} + \left(\frac{G}{2}\operatorname{cosec}\alpha\frac{S^2}{2} - \frac{P}{4}\cot\alpha\right)\right]$$

$$E = M + \frac{\cot\alpha}{2n} - G\left(1 + \operatorname{cosec}\alpha\frac{S^2}{2}\right)$$

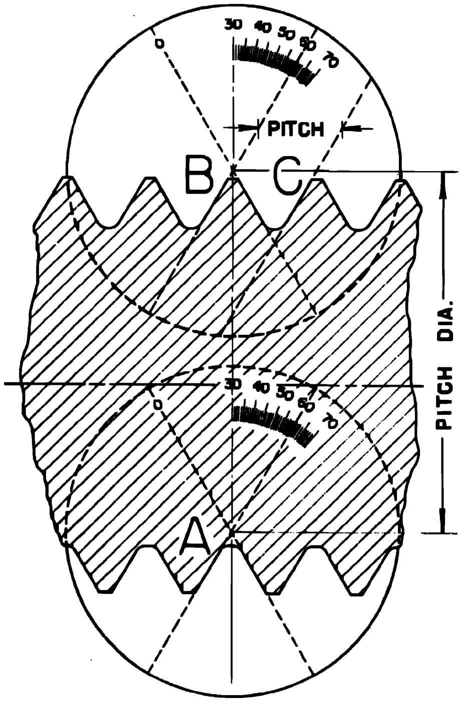


FIG. 39A. The Method of Measuring the Pitch Diameter and Linear Pitch of a Screw Thread in a Toolmaker's Microscope Using Two Independently Adjustable Cross Lines Is Shown.

At A the zero line with the 30–70-deg graduation is tangent to the left side of one thread. The single line passing through the 60-deg mark is tangent to the other side. The intersection is at the root of a theoretical V thread. At B the work has been moved so that a thread is included by the two lines which intersect at the crest of the V thread. By measuring the position of the table on the transverse screw micrometer scale at A and again at B, the difference is obtained which equals the pitch diameter. By moving the work so the line over the left side of the thread at B is now at the left side of the thread at C the linear pitch of the thread is determined.

S is small for helix angles less than 6 deg and may be neglected.

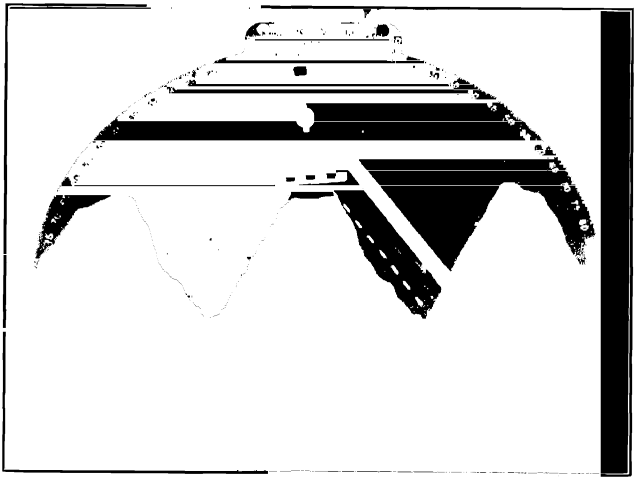
$$\therefore\ E = M + \frac{\cot\alpha}{2n} - G(1 + \operatorname{cosec}\alpha)$$

if $\alpha = 30$ deg, $E = M + 0.86603P - 3G$;

$$\text{if } G = \text{best wire size} = \frac{P}{2\cos\alpha} = \frac{P \text{ secant } \alpha}{2} = 0.57735P;$$

$$\text{then} \qquad E = M - \frac{3G}{2}$$

M is the measurement over the three wires, Fig. 35, E is the pitch diameter, and G is the diameter of the wires; all dimensions are in inches. " Best-size " wires of correct diameter for different pitches are available. They are very hard, smooth, straight, and accurate.



Courtesy Jones and Lamson Machine Co.

FIG. 39*B*. The Appearance of the Image of a Commercial Screw Thread in the Contour-Measuring Projector.

The adjustable master thread chart showing the graduated arc and Vernier has a 60-deg angle and dashed lines to indicate permissible pitch diameter tolerances.

Example: Determine whether the pitch diameter of a ⅜-in.-diam. 16 N.C. ground-thread tap is correct. Actual measurement over wires with micrometers is 0.3885 in. The diameter of the " best-size " wire is

$$0.57735P = \frac{0.57735}{16} = 0.03608 \text{ in.}$$

$$M = 0.375 - \frac{1.5155}{16} + 3 \times 0.03608 = 0.38854 \text{ in.}$$

The computed value of M corresponds with the measured, which indicates that the pitch diameter is correct.

Example: **What is the pitch diameter of a $\frac{3}{8}$-in., 16 N.C. ground-thread tap, if M = 0.3885 in. over " best wires"?**

$$E = M + 0.86603P - 3G = 0.3885 + \frac{0.86603}{16} - 3 \times 0.03608 = 0.3344 \text{ in.}$$

or

$$E = M - \frac{3G}{2} = 0.3885 - 0.0541 = 0.3344$$

Figure 39*A* illustrates how inaccuracies of commercial screw threads are detected by optical means in the **contour-measuring projector.**

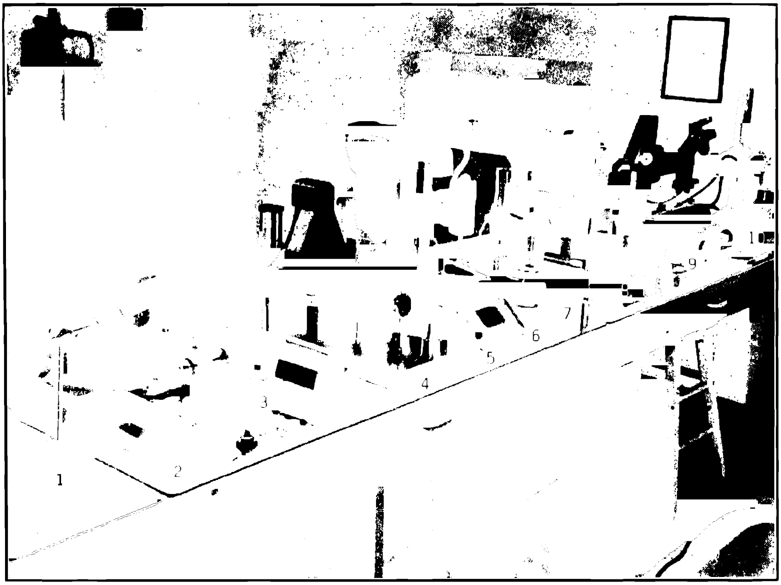


FIG. 40. A View of Equipment in the Gaging and Measuring Laboratory at the University of Michigan, Showing Various Microscopes and Comparators as Follows:

1. A Bausch & Lomb wide-field lamp.
2. A Spencer Lens Co. binocular wide-field microscope.
3. A Sheffield visual gage comparator, style 1000, reading to 0.0001 in. of 2000X magnification.
4. The B. C. Ames Co. No. 13 dial indicator comparator of 6-in. capacity.
5. DoAll Metron comparator, providing spindle pressures from 4 to 36 oz and reading to 0.000020 in.
6. Zeiss optical comparator, reading to 0.000050 in.
7. Sheffield comparator, style 20,000, reading to 0.000002 in.
8. Pratt and Whitney mechanical fan-type gage comparator, reading to 0.0001 in.
9. Gaertner Scientific Corp. Toolmaker's microscope, type M2001A, of 4- × 2-in. capacity with thread checking stage. Linear measurements to 0.0001 in. and angular to 1 min may be made.
10. Pratt and Whitney Electrolimit gage, reading to 0.000010 in.

Five hundred commercial screws can be inspected per hour for pitch diameter, root clearance, pitch of thread, crest diameter, and accuracy of lead. Cumulative errors in diameter and lead are instantly detected.

Figure 40 shows a number of microscopes and comparators in the gaging laboratory at the University of Michigan. Figure 41, another view in the same laboratory, includes a large surface plate and accessories and a number of measuring machines identified in the legend.

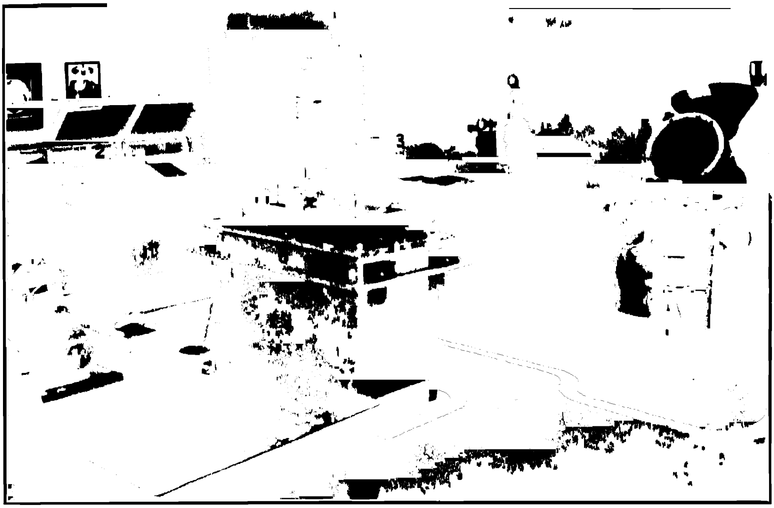


FIG. 41 A Section of the Gage Laboratory at the University of Michigan, Showing Some Precision Measuring Machines

No. 1 Pratt and Whitney Supermicrometer of 8 in. capacity, giving readings to 0.0001 in.
No. 2 Pratt and Whitney measuring machine with a capacity of 48 in., giving readings to 0.00001 in.
No. 3 Brown and Sharpe dividing head such as is used on universal milling machines.
No. 4 Vinco dividing head and base which gives readings to 1 sec. of arc.
No. 5 Jones and Lamson pedestal-type projection comparator and measuring machine.
No. 6 A master surface plate showing a variety of tools used in checking gages.

QUESTIONS

1. What is the United States standard unit of length?
2. Under what conditions are measurements of length supposed to be standard?
3. (*a*) What is the simple ratio of the inch to millimeters for industry? (*b*) Who established this ratio?
4. What is meant by a measuring instrument?
5. What is meant by a gage?
6. What are the several principles used in measuring instruments for determining linear measurements?
7. What is a limit gage?
8. Explain the use of a sine bar.
9. What is an optical measuring instrument? Give three examples.
10. What is meant by light-wave interference and how is it used for measuring the length of a part?

11. Classify gages into five main groups.

12. What is meant by basic size, tolerance, allowance, nominal size, and limits?

13. What is meant by manufacture of interchangeable parts, selective assembly, and assembly by fitting?

14. Explain the difference between shop, inspection, and master gages.

15. What is meant by a compound angle and how is it obtained in the toolroom?

16. Explain how a screw thread is measured: (*a*) thread angle; (*b*) thread lead and pitch; (*c*) pitch diameter; (*d*) which is the more accurate method of measuring the pitch diameter, the three-wire method or the projection method using a toolmaker's microscope?

17. What three methods of determining the tolerances of limit plug gages are used?

18. Design *go* and *not go* inspection snap gages for a 1-in.-diam. shaft with an allowance of 0.001 in. if the tolerance is 0.002 in., by each of the three methods used for gage designing.

19. Design a set of working snap gages for the shaft given in the above problem, by all three methods of gage design.

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CHAPTER XIX

DRIVES FOR MACHINE TOOLS

Machine tools are driven almost universally by electric motors. Each machine may be driven individually by its own motors or driven by belt from a line shaft furnishing power to other machine tools as well. The direct-drive motor may drive the machine drive shaft through direct coupling or by belt, chain, gears, or through some multi- or variable-speed transmission.

Group Versus Individual Machine-Tool Drive

Individual and group drive each has its own province where its superiority is seldom questioned. There is, however, a great middle ground. The choice should be based on the careful consideration of (1) comparative first cost, (2) total annual operating expenses, and (3) such minor advantages and disadvantages from the production standpoint as can be foreseen from experience in similar installations. **Individual drive** should be used in areas requiring overhead-crane service; on machines which would require countershafts if grouped and are likely to be moved frequently as activity in departments varies; on machines that require considerable power, say 20 hp or more, operating at a fairly full constant load; on a few machines scattered over a large area; and in instances where the requirements of production or materials handling are best met by locating machines at odd angles. Machines requiring wide speed variations also are best driven by individual drive. In complex machines, various movements are synchronized better electrically than mechanically. Working hazard is reduced and cleanliness and lighting are improved by direct-motor drive.

Group drive is most suitable where power consumption of individual machines is extremely variable, with occasional brief high peaks. Group-drive motors are often mounted overhead. This limits their size to 100 hp, or preferably not over 50 hp, as they are unwieldy to replace in case of failure. Group drive is usually more economical in fixed charges, power consumption, and maintenance. The use of a wattmeter to determine power supplied to motors is helpful in deciding whether group or individual drive is more economical. Each drive should be selected on its own merits.

Electric Motors

Most present-day machine tools are equipped with improved types of individual electric drives and controls designed to provide (1) more power, (2) higher spindle speeds, (3) greater simplicity of operation, (4) better-controlled operating flexibility, (5) improved reliability resulting in reduced maintenance, and (6) greater safety to the operator and work. The properly designed electric drive centralizes control in one or more stations which are interlocked for safety. Push buttons and small levers give the operator complete control of even the highest-powered machine tool.

Electric motors are made to operate on two types of current, alternating and direct, known as a-c and d-c. Usually power is furnished to plants in the form of alternating current, so that the majority of motors operate on this current. If direct current is needed for some specific purpose, such as operating electric chucks or d-c motors to provide extra-wide speed range or severe accelerating or reversing duty, then a motor-generator set, rectifier, or convertor is installed to provide d-c current for each d-c motor, or a single large d-c generator may be installed to operate all d-c equipment in the plant.

Horsepower Ratings

The following standard sizes of **small-power motors** of both direct and alternating current are sufficient for practically all requirements of machine tools: 1/20, 1/12, ⅛, ⅙, ¼, ⅓, ½, ¾, and 1. For the **large-power** polyphase induction motors and d-c motors the horsepower ratings are as follows: ½, ¾, 1, 1½, 2, 3, 5, 7½, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100, 125, 150, and 200.

Voltage

For d-c motors, 230 volts are most generally used. There is still some 115-volt direct current in use, however. For a-c single-phase small-power motors, 115 volts are used, as most domestic power is of this voltage and phase. These motors are also made for 230 volts. Most large-power three-phase motors operate on 110, 208, 220, 440, 550, or even 2,300 volts. Those generally used on machine tools are wired 220/440 so that they may be operated on either voltage.

Phase

In general, three-phase current is standard for power purposes. Motors up to 25 hp may be operated on single phase, as are most small-power a-c motors.

Frequency

Sixty and 25 cycles per second are considered standard for constant-speed a-c motors. Systems of 50 cycles are found in southern California and in foreign countries. Sixty-cycle motors will operate on 50 cycles at the same voltage with modified characteristics. Small very high-speed motors operate on higher frequency obtained by the use of frequency convertors or alternators.

Types of Motors

Alternating-current motors are available in a number of types of frames or enclosures as follows:

(*a*) Protected open, for most general industrial use. This type is protected against dripping liquid and falling solids.

(*b*) Splash-proof, for resisting dripping or splashing liquids as encountered in breweries, dairies, and food plants.

(*c*) Totally inclosed, fan cooled, for use where abrasives, dust, dirt, and corrosive gases are severe.

(*d*) Explosion-proof, corrosion-resisting, motor parts made of noncorrosive metals, for use in atmospheres containing gasoline, solvent vapors, or other explosive gases.

(*e*) Explosion-proof, to resist atmospheres containing grain, coal, or coke dust.

Direct-current motors are available in similar frames.

Mountings

Motors may be mounted vertically or horizontally. Most vertically mounted motors have ball-bearings. They may be attached to the machine or base by the following methods:

(*a*) Rigid mounting where center distances are fixed, as in gear drives.

(*b*) Resilient mounting to absorb the vibration of the motor.

(*c*) Rigid mounting on a hinged plate which can be raised or lowered to adjust belt tension.

(*d*) Rigid mounting on rails so that the motor can slide for adjustment.

(*e*) Flange or end mounting for direct drive to a shaft.

(*f*) The footless type for flange or vertical mounting.

Motors have various speed characteristics as follows:

(*a*) **Constant-speed** induction motors with a small speed slip of 3–4 per cent at full load, and d-c shunt motors at constant armature voltage and fixed field current.

(*b*) **Multi-speed** 60-cycle induction motors with primary winding to provide various pole groupings to give, 3,600, 1,800, 1,200, 900, 720, and 600 rpm, depending on the number of poles of 2, 4, 6, 8, 10, and

12. Full-load speed is approximately 3–4 per cent less than these synchronous-speed values.

(c) **Adjustable-speed** motors consisting of the following:

1. Adjustable-speed d-c motors are standardized for three ranges of speed having ratios of 2–1, 3–1, and 4–1. Higher ranges may be obtained. These speeds range from 600 to 1,200 and from 750 to 1,500 for the 2–1 range, 500 to 1,500 and 400 to 1,200 for the 3–1 range, and 400 to 1,600 for the 4–1 range.
2. The General Electric Co. ACA adjustable-speed induction motor operates on a-c power without any conversion equipment. It has sliding brushes to give a speed range of 3–1 for continuous operation, and up to 20–1 for intermittent operation. The designed-in shunt characteristics enable this unit to hold a set speed within narrow limits regardless of load changes. Acceleration and deceleration are smooth and quiet, and standard NEMA frame dimensions are used. The speed is controlled by a small hand wheel mounted on the motor or by a remote flexible cable with a Vernier speed indicator. The wound-rotor motors have similar characteristics.
3. The d-c motor which operates from a-c power (known as the G. E. Speed Variator) provides a speed range of 8–1 or more by varying the voltage.
4. The electronic speed variator provides a wide speed range and is used for the 15–60-hp range of motors.
5. The General Electric Co. Thy-Mo-Trol adjustable-speed electronic motor drive consists of a d-c electric motor on the machine tool, with electronic controls for converting a-c to d-c power and for varying the voltages in the field and armature, as described under 6. These electronic drives are sold commercially also as the Westinghouse Manufacturing Co. Mot-o-trol and the Weltronic. This drive gives 100–1 speed range and holds the speed regardless of load.
6. The rotary unit of motor generator with field excitor (Ward-Leonard System) controls the d-c drive motor instead of the electronic tubes for voltage control as mentioned under 4. With both the rotary unit and tube control, the voltage of the armature may be varied so that an infinite speed variation of an 8–1 range up to the base speed is obtained at constant torque. The higher range of speeds is obtained by varying the voltage in the field to give infinite speeds from base to maximum. This unit is sold as the V–S drive by the Reliance Electric and Manufacturing Co.

(*d*) When speeds lower than the synchronous are required, a gear reduction is built into the motor housing. These are known as **geared motors** and give any desired speed reduction.

Types of Motor Windings

Small-power motors are made with a large number of different types of windings to give peculiar starting and running characteristics. The small-power motor of the **universal type** is so wound that it may be used on either a-c or d-c current. The **single-phase, shaded pole** fan duty motor is designed to drive direct-connected propeller fans. A cast-aluminum squirrel-cage rotor is the only moving part. The d-c motor is a shunt or compound wound motor, which by varying the voltage of the field permits a wide variation in the speed, in steps depending on the divisions of the rheostat. The starting torque is 500 per cent of full-load torque. **Induction-type** motors are made in three general types, such as:

(*a*) **The repulsion-start, induction operating motor** is a single-phase brush lifting motor suitable for applications requiring very high starting torque with low starting current. It is suitable for driving machines with high inertia or machines having excessive friction in starting, such as mechanical refrigerators, air compressors in gas stations, pumps, conveyors, and various machine tools.

(*b*) **The capacitor-start, induction, single-phase motor** is suitable when high starting torque with normal starting current is required, as on mechanical refrigerators, oil burners, and appliances having fairly heavy starting loads.

(*c*) **The split-phase, induction motor** is a single-phase motor suitable for low starting torque, required of office, factory, and household appliances.

(*d*) **The a-c squirrel-cage, fixed-speed induction motor** is the most generally **used on machine tools.** The " off-the-shelf " design will start, stop, and reverse. The a-c motors can be reversed frequently as required in tapping, in which case a great amount of heat must be dissipated. The full-load torque in pound-feet is hp × 5,250/rpm. This **full-load torque** is developed at the **full-load speed** which is 3 or 4 per cent below the synchronous. In these motors the torque is defined at four points of the torque-speed curve as follows:

1. The **starting** or breakaway torque is about 200 per cent of the full-load torque.
2. The **minimum** or pull-up torque occurring at about 20 per cent synchronous speed is about 180 per cent of the full-load torque.
3. The **maximum** or pull-out torque occurring at about 80 per cent of synchronous speed is about 300 per cent of full-load torque.
4. The **full-load torque** of 100 per cent occurs at the full-load speed.

These motors are designed with several different characteristics as follows:[10]

(*a*) The standard general-purpose Design B motors have low starting current, normal torque, and normal slip. Their field of application is broad and includes the driving of fans, blowers, pumps, and machine tools. These motors are usually provided with clutches so that the motor obtains full speed before picking up the load or on machines where the starting load is light.

(*b*) Design C motors having high breakaway torque, low starting current, and normal speed slip are advantageous for hard-to-start applications, such as driving plunger pumps, conveyors, and compressors. The breakaway torque of 225 per cent of full-load torque is usually higher than the maximum or pull-out.

(*c*) Special-purpose motors, Design F, have lower torque than type *a* above at all points except at full load. Their field of application is found where starting current limitations are severe and both breakaway- and maximum-torque requirements are low, as when required to drive fans and compressors with unloading devices and for the smooth starting of low-inertia machines such as sanders and band saws.

(*d*) High-slip motors, Design D, have high starting and pull-up torque for continuous use. The slip of 7–15 per cent with a starting torque of about 300 per cent full load is recommended for continuous use on machinery such as presses, shears, bolt headers, and heavy-inertia machinery, where it is desired to make use of the energy stored in a fly wheel under conditions of heavy fluctuation of load.

(*e*) High torque, very high-slip motors, Design D, for intermittent use as for rapid traversing and for high loads for short periods of time.

(*f*) High torque, many reversal motors for direct drive on drilling and tapping machines requiring 40–60 reversals per minute.

Motor Specifications

In specifying any motor, the horsepower, speed, and power supply consisting of the phase, frequency, and volts should be given. The duty, whether continuous, intermittent, or reversing, should be described. The type of enclosure or frame, such as open, drip-proof, totally enclosed, or explosion-proof, and the application of the motor should be indicated. The frame size should be specified so as to make sure that it will be interchangeable with other motors which replace it, as motors of a given rating may be in different frame sizes. Special features should be described: single- or double-end shafts, plain or ball-bearing, and mounting — whether horizontal or vertical, and whether on a fixed or resilient base.

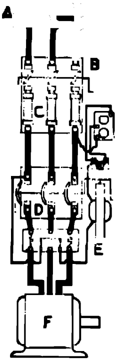
Units for Motor Control

For installing motors, a variety of accessories is needed. The diagram of a motor circuit, Fig. 1, shows the normal setup of a motor for machine-tool operation, consisting of the following in order:

A, the three-line power supply.
B, the motor circuit-disconnect knifeswitch.
C, fuses or circuit breaker (provides short-circuit protection).
D, motor starter (magnetic or manual).
E, relay heaters (to provide overload protection).
F, the motor.

The **knifeswitch** makes it possible to disconnect the whole circuit of the machine for maintenance work. Sometimes the **fuses** are placed with others in a centralized panel, in which case the fuses are "hot," being in front of the knifeswitch located at the machine. Protection to the motor, starter, and heaters against short circuits must be provided by means of these line fuses or circuit breakers, which open the circuit immediately when excessively heavy currents are encountered.

The **starter** for any given motor should have a horsepower or amperage rating equal to or greater than that of the motor. The voltage ratings, phase, and current characteristics of the starter should correspond to the power circuit. Most starters have thermal overload relays of the melting alloy, bimetallic, or magnetic coils in oil-dashpot types. They are normally closed, so that in the event of overload the heat from the relay "heater" throws the starter into "off" position. Some of these thermal relays may be reset manually, and some may be automatic. In case of repeated disconnection through the heater, the system should be carefully examined, as the machine may be overloaded or the wiring incorrectly installed.



Courtesy Trumbull Electric Manufacturing Co.

FIG. 1. Diagram Showing How the Power Supply for Three-Phase Induction Motor is Taken from the Power Line *A*, Passed through the Motor-Disconnect Switch *B*, through the Fuses or Circuit Breaker *C*, Then through the Magnetic Motor Starter *E* and *D*, through the Relay Heaters *E*, to the Motor *F*.

The push-button start-and-stop manual starter is shown to the right of the fuses.

Many generally used electrical devices are available for motor and cycle control, as follows. **Starters** may operate on the power circuit or on a reduced voltage control circuit. **Limit switches** operate mechanically to initiate a function during the machine cycle by opening or closing pilot control circuits. **Selector switches** determine the sequence of operations and at times make parts of the control system inoperative. **Timing devices** are used to slow down one sequence of operation in relation to another, allowing one function to take place ahead of the other, and **counters** are used to predetermine a number of operations to take place before another series of operations can be performed. **Solenoids** furnish a means of obtaining straight-line motions of limited stroke and power. They are used to operate line contactors and control valves when energized by means of a push button or limit switch.

Float switches, pressure switches, magnetic clutches, magnetic brakes, indicating lights, and microswitches to determine length of travel are used in many electrical circuits. **Terminal blocks** group all power and control wiring in the control panel for external connection.

A **relay** consists of contact points, normally closed or open, and a solenoid which can be operated from some outside source, such as a start button, a limit or basic switch, or a thermal or pressure element. Basic switches may be actuated in many ways, such as by stops on a machine tool slide to determine the end of the movement, a change in rate of feed, a door open or a fixture closed, and lighting a pilot light. An **overload relay** is a device which operates at a predetermined current value to open a magnetic circuit of a contactor or to trip a mechanical device for breaking the line circuit. These relays may be instantaneous or have a time delay dependent upon the excess of current above a predetermined value. They may be of the magnetic or thermal type. The former is tripped by the magnetic pull of a solenoid, and the latter by the heating effect of current passing through a thermal element. This heat may bend a bimetallic strip or melt an alloy and release a ratchet and latch.

A **push-button starter** furnishes the safest and easiest way of starting and stopping a motor, Figs. 1, 2, and 3. When a reduced voltage starter is used, the accelerating period is predetermined and not controlled by the operator. A push-button station is small and can be mounted at a point convenient for the operator. Starters can be manually, magnetically, float, or pressure-switch operated. The simple manual start and stop starter has two push buttons or a single lever. Other buttons may be added for reversing, magnetic breaking, plugging, or jogging. Starters are available in several types of enclosures, such as the general-purpose, water-tight, semi- and fully dust-proof, and explosion-proof. Push-button starters also are used to operate electrically controlled, hydraulic or pneumatic equipment and accessories which perform some function such as work clamping or opening and closing guards.

Three-wire-control starting involves a start-stop push-button starter and solenoid contactor all working on the primary circuit as shown in Fig. 1. The closing of the start-button contact completes the starting circuit, and the contactor closes the circuit through the stop contact which is normally closed. When the stop contact is opened the contactor opens and the motor circuit is broken.

Figure 2 shows a control circuit for a single motor of the three-phase induction type, such as one used on a machine tool. The power circuit is of 440 volts, 60 cycles, and 3 phase. A transformer is used to reduce the power voltage from 440 volts to 110 volts, on which the control circuit operates for safety to the operator and for longer life of the contact points. The start button closes the circuit C_1-C_2 which causes the coil of the magnetic starter in the primary to close. Thermal overloads *TO* are indicated to protect the motor from excessive heating. When these operate, they open the normally closed (*NC*) switches which release the normally closed stop button.

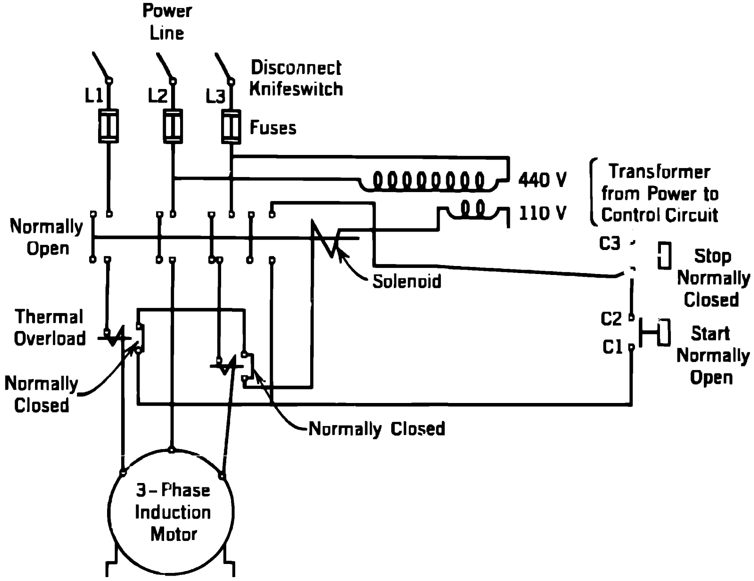


FIG. 2. A Line Diagram of the Start-and-Stop Control Circuit for Furnishing Power to a Single Motor.

The start button is normally open (N. O.).

Figure 3 shows a similar diagram for two interlocked motors of a machine, so that if the spindle motor is stopped the feed motor also will stop.

Mechanical Variable-Speed Transmissions

There are a number of devices now used, of both the mechanical and hydraulic types, which will provide speed changes over a wide range. These devices usually are placed between the motor and the machine. The mechanical devices consist of the multispeed and infinitely variable-speed types. The former are usually of the sliding-gear type, built as a separate unit or as a unit integral with a motor up to 25-hp capacity, such as the **Lima**, to give four speeds. The **Drive-All** gives three or four speeds and is belt-driven by a motor mounted at the rear. The variable-speed or output shaft drives the machine.

The Reeves Pulley Co.'s **Vari-Speed transmission** and the U. S. Electrical Motors Co.'s **Varidrive,** Fig. 4, furnish infinitely variable speeds over a wide range. The constant-speed motor drives a pair of opposed cone pulleys on its extended shaft, at a constant speed. A belt with beveled edges connects this set of pulleys to a second set. As the hand wheel is turned, one set of pulleys is moved apart and the second set is moved together. As the effective pitch diameter of the constant-speed set of pulleys is increased, that of the second set is reduced and the rpm of the driven shaft is increased. The Master Electric Co.'s **Speed Ranger** operates on the principle of two pairs of opposed cone pulleys. A steel ring having beveled internal edges to match the cone angles serves as a belt. The Graham Variable-Speed drive has a built-in motor to drive a rotating planetary gear system. This system carries two tapered rollers bearing against a nonrotating ring

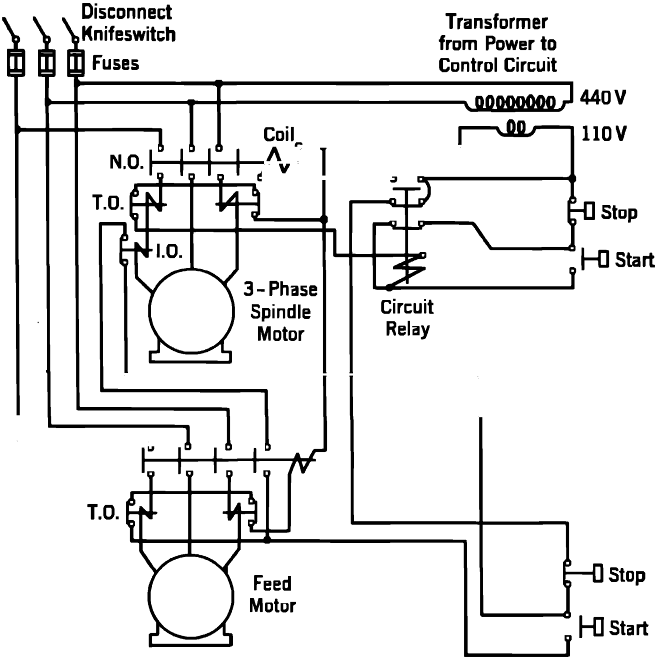


FIG. 3. A Line Diagram of a Start-and-Stop Control Circuit for Furnishing Power to the Spindle Motor of a Milling Machine.

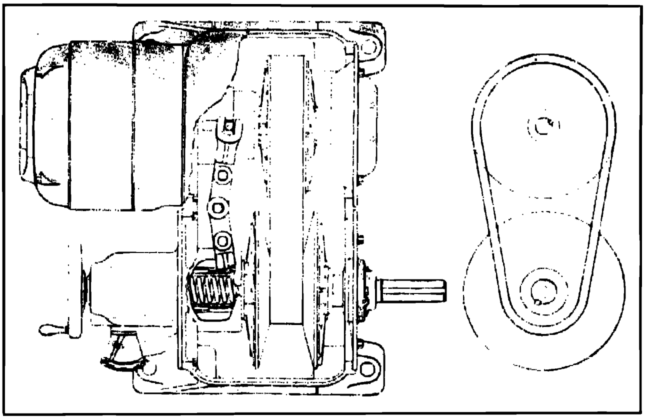
A separate start-and-stop control circuit is provided for the table feed motor. This also shows how an instantaneous overload (I. O.) will open the circuit of the feed motor should the spindle motor be stopped.

Thermal overload (T. O.), instantaneous overload (I. O.), and circuit relay (C. R.).

which provides infinitely variable speeds to the output shaft as it is moved along the tapered rollers. The Allis-Chalmers Manufacturing Co.'s **Vari-Pitch** sheaves operate with V belts. The pitch of the sheave can be varied to give any desired belt speed by bringing the opposed cones of the pulley together for greater pitch diameter and by moving them apart for smaller diameter.

Hydraulics for Machine Tools *

Hydraulic-oil feed or speed mechanisms are being used increasingly on metal-cutting and forming machines. If straight-line or reciprocating motion is desired, the pressure is applied to a piston in a cylinder. If rotary motion is desired, the pressure is applied to some form of rotary engine. The rate of movement or feed of the work is controlled by the volume of oil used.



Courtesy U. S. Electrical Motors Co.

FIG. 4. The Flange-Mounted, Constant-Speed Motor, Built Integral with the "Varidrive" Variable-Speed Transmission.

The effective driving diameter of the pulleys is changed by moving the cone pulleys of one set together and those of the second set apart. The unit, as shown, is set for high output speed.

In a **typical cycle** for feeding, as in the case of a drilling head or milling table, the table may (1) advance rapidly to engage the tool and work, (2) change to power feed for the cut (this feed may be constant or varied in the cut to suit the condition), (3) dwell at the end of the cut to clean up, (4) return rapidly to the starting position, and (5) stop or repeat the cycle. A typical circuit is illustrated in Fig. 5.

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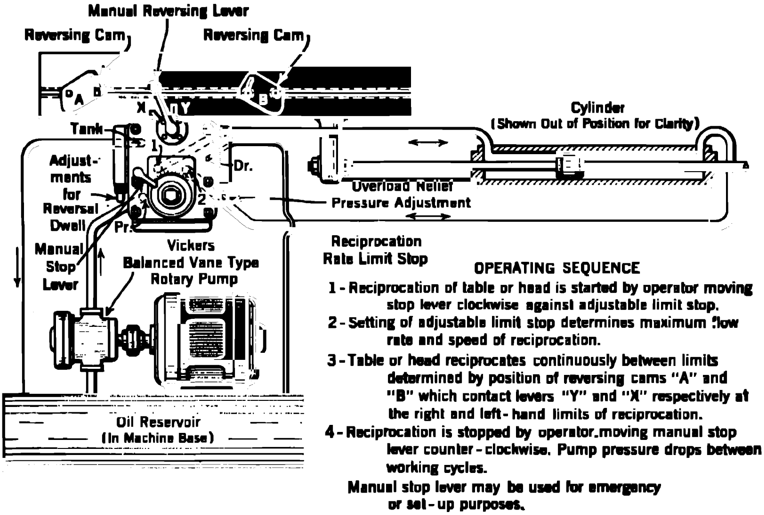
* Taken largely from a paper, "Hydraulics for Machine Tools," by Mr. M. J. Taub, Vickers, Inc., with his permission.

Within the machine-tool field there are various subdivisions of hydraulic power application and control as defined by the type of machine or process, such as turning, milling, grinding, boring, drilling, molding, and pressing. Although characteristic requirements are common to several or all of these, each one will be found to use one or more types of control units more frequently than the others. Accordingly, some pumps and valves become more or less identified with a class of application.


Manual Reversing Lever
Reversing Cam
Reversing Cam
A
B
X
Y
Tank
1
Adjustments for Reversal Dwell
Dr.
2
Pr.
Manual Stop Lever
Vickers Balanced Vane Type Rotary Pump
Cylinder (Shown Out of Position for Clarity)
A
Overload Relief Pressure Adjustment
Reciprocation Rate Limit Stop
Oil Reservoir (In Machine Base)

OPERATING SEQUENCE

1 - Reciprocation of table or head is started by operator moving stop lever clockwise against adjustable limit stop.

2 - Setting of adjustable limit stop determines maximum flow rate and speed of reciprocation.

3 - Table or head reciprocates continuously between limits determined by position of reversing cams "A" and "B" which contact levers "Y" and "X" respectively at the right and left-hand limits of reciprocation.

4 - Reciprocation is stopped by operator moving manual stop lever counter-clockwise. Pump pressure drops between working cycles.

Manual stop lever may be used for emergency or set-up purposes.

FIG. 5. Diagram of a Typical Hydraulic Circuit as Applied to a Machine Tool in Which a Constant-Delivery Pump Is Used.

Vickers series C-1286 panels are used to cause the reciprocation of table or head.

Each of these processes has one or more peculiarities, some of which are as follows:

Turning inherently requires accurate feed rates, and in addition almost as universally requires quick approach of the tool to the work (or the work to the tool) and, probably, rapid retraction.

Milling includes the above but immediately branches into out-cut or in-cut milling. Particular attention must be given to this practice to avoid tool breakage.

Grinding usually requires a constant, uniform reciprocating cycle and exhibits the need for smooth accurate reversals.

Boring is very similar to turning and in some cases to milling, but in the large machine, handling work several feet in diameter, it frequently demands jump feeds. Provision for this requirement avoids costly lost time due to rotating the work at feed rate during the time no useful work is being done, as when the tool clears a pad and will not work again until the next one rotates around to it. Accordingly traverse speed is provided for this portion.

Drilling requires many of the foregoing features, but one peculiarity is the tendency for the drills to pull forward as they break through. This is similar to in-cut milling, and both require a retarding force in most cases.

Pressing can be any of many types such as forming, straightening, extruding. The outstanding characteristic is its usual requirement for more power, hence more consideration of control of the power to avoid undue heat.

Every circuit requires a power source, and in this field it is a pump; electrically it is the motor. Provision must be made to prevent overloads, so the next requirement is a relief valve or pressure control comparable electrically to a fuse. Then, to use the power available, something must be provided to control the direction of fluid flow, hence some form of directional valve comparable electrically to any of a variety of switches.

Many types of valves are used, but always as modifying factors. They provide for the intermediate actions and precision control dictated by the specific application. In addition there are certain provisions for fluid flow which are considered good practice. Except under unusual circumstances, it is well to select the pipe or tubing size to provide rates of about 2–5 fps in suction lines, and not more than 15–20 fps in pressure lines. Exceeding the former rate is apt to lead to cavitation, and the latter may lead to undue pressure loss.

Fluid temperature is normally considered best at 90–130° F. In aircraft and mobile applications there may be a wide variation in ambient temperatures. Temperature variation is important, and since all slippage varies with temperature, a balance must be attained at some reasonable point. The oil industry has formulated fluids of various characteristics adaptable to the conditions encountered. A hydraulic oil of 200–250 SSU at 100° F is generally used.

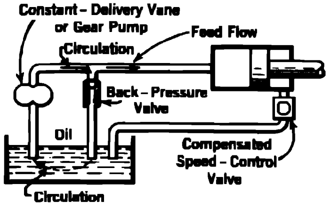
There are no fixed rules as to when cooling provision should be incorporated by the designer of the machine. He has several factors to contend with, among them the inherent characteristic of the machine as judged by its operating cycle; the size and location of the reservoir; and the overload that will be imposed. Previous experience is a fairly good guide, but special provision should be made if more than an average of 2–3 hp in the form of heat is to be dissipated. This assumes reasonable air circulation and a capacity approximately twice that of the pump in gallons per minute, but in no case less than 15–20 gal. The design should be modified in terms of greater or less tank capacity and be in conformance with any unusual insulation conditions which may exist.

Factors involved in the determination of heat are pressure values and their duration at various levels, pump and valve efficiencies, cycle characteristics, and type of pumps and valves selected. Operating pressures vary rather widely in terms of the over-all machine-tool industry, but there are certain ranges which have become identified with types of machines. Turning, boring, drilling, and milling systems usually operate at 500–1,000 psi. Grinding seems to lend itself to pressures of 200–300 psi. Molding machines are most frequently satisfied at 800–1,000 psi. Presses most often work in the range of 1,000–3,000 or possibly 3,500 psi.

The range of operating speeds varies rather widely, and there are no definite rules to follow. The operation to be performed, the mass to be moved, the cycle, reversal requirements, etc., all enter into determining whether there are particular limits. In general the maximum allowable speed is somewhat greater than that demanded by the operation and therefore does not represent a problem. However, improper selection of valve sizes can cause difficulty even when the speed itself is well within range.

Feed rates are controlled by either of two methods. Selection of the method is governed primarily by the amount of power involved and the feed rate. The first method is to use a **constant-delivery pump** in conjunction with a flow-control valve, Fig. 6. This system allows only the amount of fluid consistent with the speed or feed rate desired to reach the cylinder. The second method is to use a **variable-delivery pump** which can be adjusted to deliver the exact quantity required, as illustrated in Fig. 7. The former is usually practical up to 4 or 5 hp, but under particular circumstances can be used appreciably beyond that. In the low horsepower range it is usually more practical as well as more economical to use the constant-delivery pump. Above 10–12 hp the variable-delivery pump will probably prove to be both more practical and more economical. In the range of 5–10 hp the decision must be based on the operation requirements, initial and operating cost.

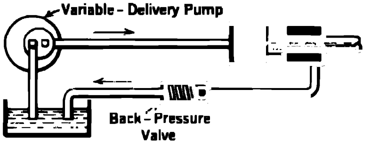
The feed rate may be governed either by the pump displacement or by a compensated flow-control valve. With metering-out systems, Fig. 6, the flow-control valve serves to lock the piston between two columns of oil; the back pressure on the exhaust side of the piston varies inversely as the work resistance and prevents overfeed when the tool " breaks through " or during in-cut milling. The pressure on the pump or pressure side of the system is generally constant, preadjusted to the maximum thrust requirements of the tools. With metering-in systems, Fig. 7, a constant back pressure must be maintained on the exhaust oil from the cylinder to lock the piston and prevent overfeed when the tool tends to pull ahead into the work, such as when breaking through when drilling. With such systems the pressure on the pump or pressure side of the piston is equal to the tool resistance plus the preadjusted back pressure.


Constant-Delivery Vane or Gear Pump
Feed Flow
Circulation
Back-Pressure Valve
Oil
Compensated Speed-Control Valve
Circulation

By F. T. Harrington.

FIG. 6. Diagrammatic Hydraulic Feed with Constant-Speed Constant-Delivery Pump, Metering-Out Circuit.

Reversing circuit is not shown.



By F. T. Harrington.

FIG. 7. Diagrammatic Hydraulic Feed with Constant-Speed Variable-Delivery Pump, Metering-In Circuit.

Reversing circuit is not shown.

In terms of feed or speed rate, there is essentially no maximum limit, but consideration must be given to minimum speeds. The usually accepted minimum flow rate is about 5 cu in. of fluid per min. This, converted to inches per minute at the cylinder based on the effective working area of the piston, represents the minimum in any specific case. In general, speeds below ½ in. per min at the cylinder cannot be controlled with any degree of accuracy.

Obtaining the desired cycle as well as the required precision, power, and traverse speeds necessitates careful selection of pumps and valves.

The **first step** in narrowing down the group of pumps and valves from which the selection finally will be made is based on the type of application. Once the application is fully understood the **second step** is the determination of those functions to be performed hydraulically and their relation to the balance of the machine operation. This involves the definition of the exact operating cycle. It will be necessary then to know whether the cycle is to be controlled manually or whether it will be automatic or semiautomatic. Speeds must be established for feed and traverse. In addition, the forces and power required must be determined, after which the basic control circuit can be laid out. Selection of the pump and valves is then a matter of meeting the speed, pressure, and control requirements.

There is as yet no universally accepted nomenclature covering the various types of pumps and valves in their entirety; however, those more commonly used are included in the following list. There are several thousand distinct sizes, types, and modifications.

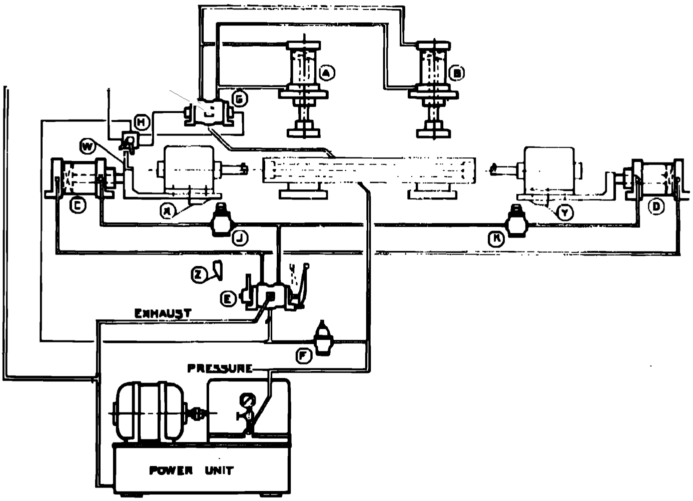
1. Types of pumps are as follows:
   (*a*) Gear, constant displacement
   (*b*) Vane, single-stage constant displacement
   Combination of 1 small high-pressure and 1 large low-pressure pump
   Two-stage constant displacement with 1 pump supercharging the other
   (*c*) Piston, axial or radial, can be either constant or variable displacement.
2. Pressure-control valves are for various purposes as follows:
   (*a*) Relief valve, direct spring loaded or remote spring loaded with fluid control
   (*b*) Sequence valve
   (*c*) Time-delay valve
   (*d*) Pressure switch
   (*e*) Unloading valve
   (*f*) Counterbalance valve
3. Directional-control valves may be 1, 2, 3, 4, 5, or 6 way and of the following types:
   (*a*) Electrically operated
   (*b*) Manually operated
   (*c*) Pilot operated
   (*d*) Shut-off (deceleration) valve
   (*e*) Check valve
   (*f*) Prefill valves
4. Flow-control valves:
   (*a*) With relief valve: Control oil to fluid motor or cylinder
   Control oil from fluid motor or cylinder
   (*b*) Without relief valve: Bleed off to reservoir
5. Fluid motors of the rotary type:
   (*a*) Gear, constant displacement
   (*b*) Vane, constant displacement
   (*c*) Piston, variable displacement and constant displacement
6. Cylinder for providing speed, feed, or clamping

Such units as panels in which particular combinations of the foregoing are grouped into one body are not included above, since these can all be duplicated by proper selection of separate units. Primarily these panels serve to facilitate installation, reduce piping and installation cost, and improve appearance, but they are basically complete circuits composed of the separate units with drilled and cored passages replacing pipes as shown in Fig. 5.

Since there are few fixed and firm rules governing the application of hydraulic controls, it is somewhat difficult to select and illustrate some one circuit applicable to more than limited cases. The following are three examples based on specifications selected at random. The first two might apply in whole or in part to drilling, reaming, boring, milling, or turning. The third might be considered a basic forming press of fairly large tonnage.

Example 1: The hydraulic circuit for operating four cylinders, two for clamping a bar and two for feeding in electric motor-driven boring heads at each end, is shown in Fig. 8.

The circuit operates as follows: At the time of loading, the clamping cylinders, *A* and *B*, and the work-head cylinders, *C* and *D*, are in the retracted position as shown. The operator shifts valve *E* to position No. 1, thus directing the pressure

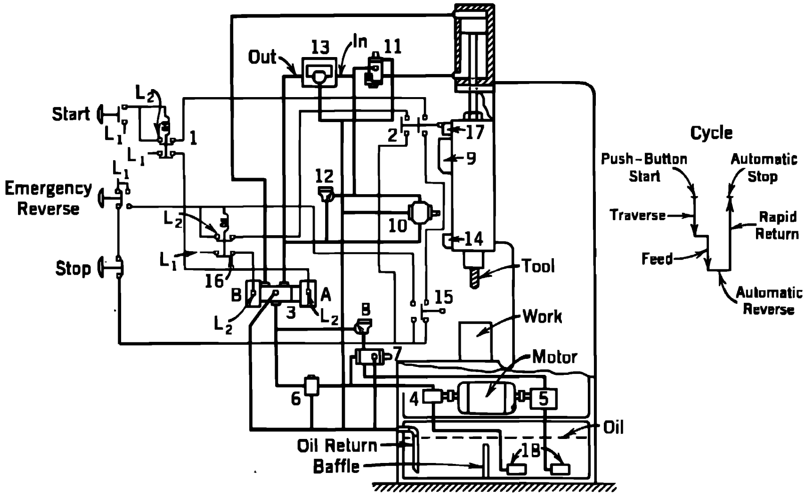


Courtesy Harry L. Stewart.[18]

FIG. 8. A Hydraulic Circuit for Operating Two Clamping Cylinders and Two Feed Cylinders for Boring the Ends of a Tube.

A standard packaged power unit is used, which consists of a hydraulic pump driven by a coupling connected electric motor, all mounted on the top of an oil reservoir.

from the motor-driven pump to the head end of the boring-head cylinders, causing the boring heads to advance toward the work. Almost simultaneously, the trip dog actuates valve *H* to reverse valve *G*, thus directing the fluid pressure to the head end of the clamping cylinders, *A* and *B*. While the clamping heads are advancing, the work heads *C* and *D* are at rest, being held momentarily by action of the sequence valve *F* actuated from *G*. After the work piece is firmly clamped, the built-up pressure again opens valve *F*, permitting oil to flow through valve *E* to the work-head cylinders, *C* and *D*. The work heads then continue their traverse toward the work, rapidly at first, until the straight-line cams *X* and *Y* actuate valves *J* and *K* to reduce the traverse to feed. Head *C* should be somewhat later than head *D* to permit the latter to complete its work stroke first. When work head *C* completes its work stroke, the latch on valve *E* is released by trip *Z* and valve *E* is reversed, causing work heads *C* and *D* to retract rapidly. Near the end of the return stroke the trip dog actuates valve *H* and reverses valve *G*, causing the clamping heads *A* and *B* to retract and release the work, at which time all action ceases.



By M. J. Taup.

FIG. 9. The Electrical Circuit and Hydraulic Layout for an Electrically Controlled, Hydraulically Operated Drilling Machine to Perform the Cycle Indicated at the Right.

The names of the various units are numbered as follows: *1.* Relay; *2.* limit switch; *3.* solenoid-operated directional 4-way spring-centered valve; *4.* pump, small-volume high press; *5.* pump, large-volume low press; *6.* relief valve; *7.* unloading valve; *8.* check valve; *9.* adjustable cam; *10.* shut-off valve (depress to close); *11.* counterbalance valve; *12.* check valve; *13.* flow-control valve; *14.* adjustable cam; *15.* limit switch; *16.* relay; *17.* adjustable cam; *18.* suction filter.

Example 2: The electrical circuit for a hydraulically operated machine tool for drilling (or reaming, boring, turning, or milling) is shown in Fig. 9. The cycle is to be as follows: manual push-button start with rapid traverse until the tool has reached the work; power feed is engaged and continues to the end of the working stroke. There is automatic withdrawal of the tool and rapid return to the starting point, where the machine is automatically stopped. This cycle is shown diagrammatically at the right of the illustration. Emergency reverse and stop buttons are included in the electrical circuit.

The various electrical and hydraulic elements are listed in the legend of Fig. 9. A description of the cycle is as follows:

The cycle is started by depressing the start button. This energizes relay *1* and in turn solenoid *A* of valve *3*. Holding current for the relay is obtained from limit switch *2*. Since, at the instant of start, the latter is shifted, the start button is held for an instant until the cam drops off the switch, permitting it to close.

Energizing *A* directs the fluid from both pumps *4* and *5* through valve *3* to the head end of the cylinder. Fluid from pump *4* passes through valve *6*, which is adjusted for the maximum desired system pressure. At this point it combines with fluid from pump *5* which passes through valves *7* and *8*. Therefore during this phase of the cycle the cylinder piston advances at rapid traverse rate.

The exhaust fluid passes through valves *11* and *10* and *3* to the tank. Valve *11* serves to counterbalance the weight of the head to prevent gravity drop.

As the head moves down, cam *9* depresses the plunger of valve *10* just before the tool reaches the work. This shuts off the flow through *10*, the fluid is checked at *12*, and the route is then through *13* and *3* to the tank. Valve *13* is adjusted to meter the fluid from the exhaust side of the cylinder at a rate consistent with the desired feed rate.

With the flow control in operation, the quantity of fluid required at the head end of the cylinder is less than the capacity of pump *4*; consequently the oil pressure will build higher than the setting of valve *7*. The latter is set just high enough for traverse, and as a result it opens and fluid from pump *5* returns directly to the tank at circulating pressure. Valve *8* closes at that time and prevents back flow from pump *4*.

On completion of the power stroke, cam *14* depresses the limit switch *15*, which in turn de-energizes relay *1* and solenoid *A*. At the same time it energizes relay *16* and solenoid *B*. Valve *3* then directs fluid from both pumps *4* and *5* through valves *12* and *11* to the rod side of the cylinder for rapid return. Valve *12*, being a check valve, permits free flow in the direction of the arrow and by-passes both valves *10* and *13* without restriction.

On completion of the return stroke cam *17* depresses the limit switch *2*, which removes the current from relay *16* and in turn solenoid *B*. Valve *3* then returns to neutral, and the fluid from both pumps passes through it directly to the tank at circulating pressure.

Push-button reverse and stop are matters of proper electrical hook-up to obtain the action described for the automatic cycle.

Example 3: The layout of the hydraulic equipment for a large forming press is shown in Fig. 10. The specification is that the control is manual. A rapid traverse of the platen until it reaches the work is required. An automatic change of traverse speed to pressing speed occurs at the time contact is made by the platen with the work. A description of the cycle follows:

The cycle is started by shifting the lever of valve *3* to direct the fluid from pump *1* to the head ends of the traverse cylinders.

As contact is made with the work, pressure is built up, causing valve *5* to close and directing the fluid from the pump to the main ram cylinder as well as to the two traverse cylinders. During the traverse portion of the stroke, valve *5* is open to permit free flow of the fluid from the tank into the ram cylinder for prefilling purposes.

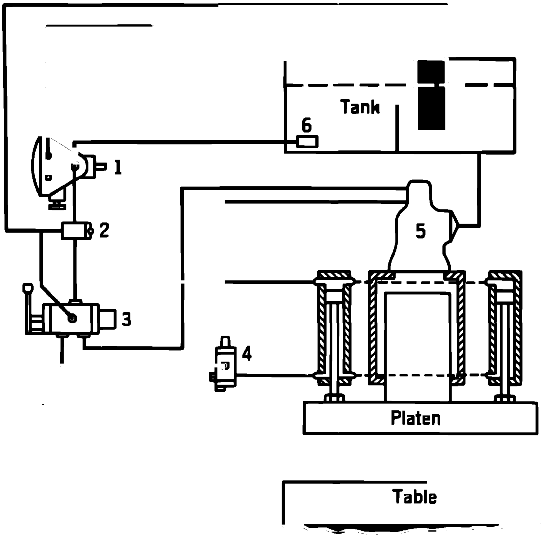
On completion of the forming stroke, valve *3* is shifted to direct the fluid to the rod ends of the traverse cylinders, causing them to lift the platen.

At the end of the return stroke, valve *3* is moved to neutral, at which time the fluid from the pump goes directly to the tank at circulating pressure.

Valve *5* opens for the return stroke, permitting the fluid in the ram cylinder to flow directly to the tank.

Valve *4* serves two purposes; first it prevents gravity drop of the platen during the advancing stroke, and second it holds the platen in the "up" position during idle time.

Pressure, and in turn the press tonnage, are determined by the adjustment of valve *2*.



By M. J. Taup.

FIG. 10. The Diagram of a Hydraulically Operated, Heavy-Duty Press, Which is Manually Controlled with Automatic Change from Traverse Speed to Pressing Speed at the Time of Contact between the Platen and Work.

A variable-delivery pump is used. The units are numbered as follows: *1*. Variable-delivery pump; *2*. relief valve; *3*. manually operated 4-way valve; *4*. counterbalance valve; *5*. prefill valve; *6*. suction filter.

Pumps for Machine Tools

Many different forms of hydraulic pumps are in commercial use. They may be classified under three main headings as the gear pump, the vane pump, and the plunger pump. The gear- and vane-type pumps are used most often where the hydraulic power required is not excessive and where maintenance of a set feed rate is not so important, or where the rate of motion does not vary extensively. A **gear pump** is shown in Fig. 11. The gears rotate in mesh. Usually one gear is the driver. At the point of contact the motion is toward the suction side, so that oil is trapped in the space between the gear teeth and carried around the periphery to the discharge side, where it is released against any built-up pressure. Spur, helical, or herringbone gears are used in this type of pump. The gears fit closely into the housing both on the periphery and on the ends.

The Gerotor pump is a special type of **internal-gear pump,** Fig. 12. The larger internal gear is driven by the pinion. The outer gear is free to rotate but is snugly fitted into one end of the housing. The tops of all teeth of the inner gear are in sliding contact with those of the outer gear. Oil-tight pockets are formed by the teeth of the gears, and because of their eccentricity the pockets change volume from zero to maximum and again to zero during each revolution. One end of the housing carries openings, one of which is a suction port where oil is drawn into the increasing space and the other is the discharge port from which the oil is forced. Deliveries range from 0.4 gpm at 1,800 rpm to 40 gpm at 1,200 rpm at 1,000 psi or higher.

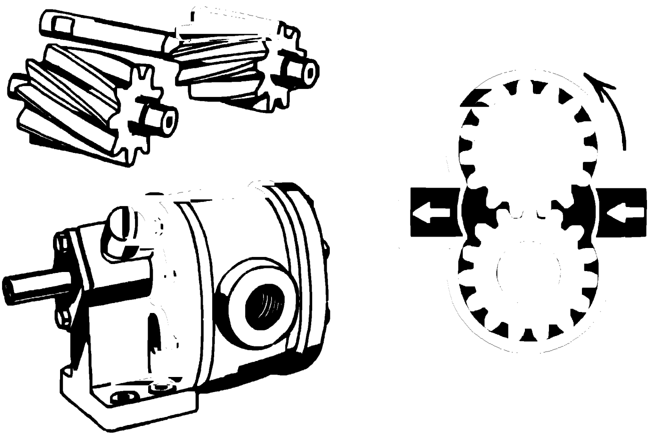


FIG. 11. A Typical Illustration of a Gear Pump, Lower Left, with the Helical Gears at the Upper Left and the Diagram Showing the Fluid Flow at the Right.

A **vane-type pump,** illustrated in Fig. 13, is a low-cost unit and with proper control gives excellent service in many hydraulic applications. The vane pump has a rotor carrying nearly radially placed vanes. This rotor with the vanes is rotated within the stationary, specially shaped outer ring. The vanes are free to slide radially in and out of the rotating hub and so maintain contact with the outer ring. Oil ways from the high-pressure side of the pump to the space at the inner end of the vanes maintain this contact. The suction ports are located in the end plate at a point where the outer ring recedes from the rotating hub, and the discharge ports are located at a point where the outer ring approaches the hub. With close tolerances among the vane, hub, and case, these pumps are capable of developing very high pressures. The

Vickers pump, illustrated in Fig. 13, is a constant-discharge pump. This pump is made as a single-stage pump or as a combination pump utilizing a small and large vane pump in the same housing, so that the discharge from the small pump, the large pump, or the combination of the two can be used as desired. The combination pump is shown in Fig. 14, which also shows, below, the Vickers two-stage vane pump for hydraulic working pressures from 1,000 to 2,000 psi.

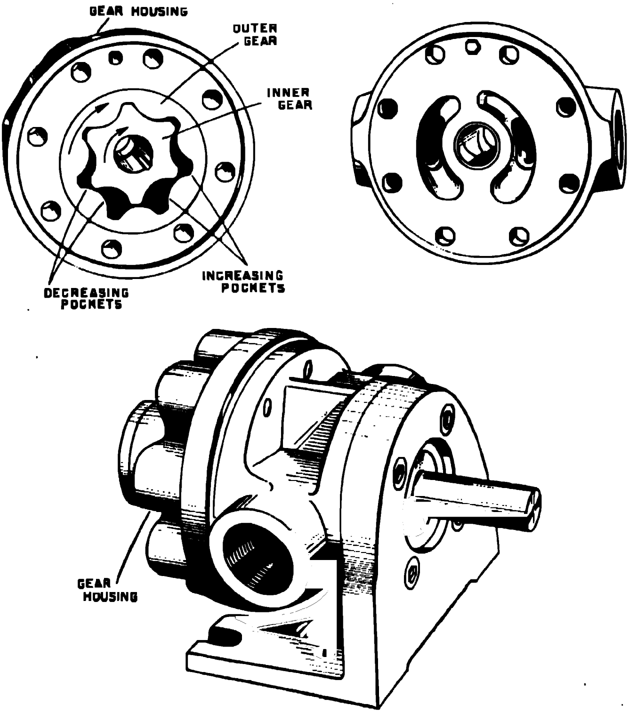


Fig. 12. The Two Eccentric Internal Gears with the Two Ends of the Housing of the Gerotor Pump Together with the Assembly Are Shown.

The **accessories** most generally used with these pumps consist of: four-way valves operated manually, mechanically, or by solenoids; sequence valves, pressure-reducing valves, relief valves, check valves, pilot valves, time-delay valves, and flow-control valves.

The Racine Tool and Machine Co. make a vane pump in which the rotating ring is circular rather than formed and is mounted flexibly in a housing so it can be moved radially to change the stroke of the vanes during each revolution. This control provides the variable discharge.

In applications where the rate of traverse of the driven member must be varied within wide limits and where hydraulic leakage must be kept to a minimum, the variable-displacement plunger-type pump is used. These plungers may be mounted radially or axially in a housing. The former is represented by the Oilgear pump and the latter by the Sundstrand and Vickers, Fig. 15. The plungers may be cylindrical as in the Vickers and Oilgear pumps, or they may be flat such as those used in the Racine variable-displacement pump. These pumps may be made with constant or variable length of stroke. The Oilgear pump obtains the variable length of stroke by shifting the housing against which the outer ends of the pistons bear as they rotate eccentrically, in a way similar to the method employed in the Racine variable-displacement pump. The Sundstrand and Waterbury axial-type plunger pumps use a swiveling wobble plate against which the ends of the plungers bear to secure variable displacement. If the angle of the wobble plate is changed, the discharge of the pump is altered, but if the wobble-plate angle is fixed and the quantity of oil delivered to the pump or motor is altered, its rotating speed is changed.

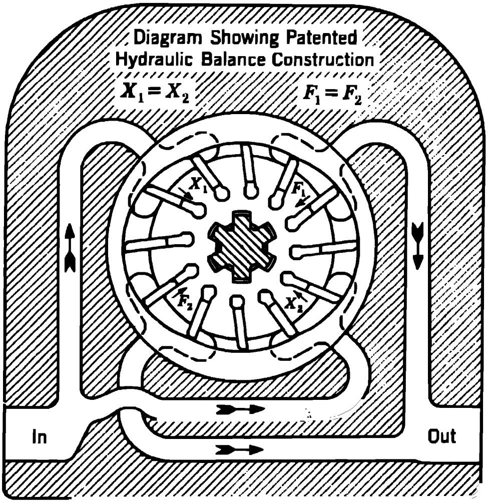


FIG. 13. A Sectional View of the Vickers Vane Pump.

This is a constant-discharge pump with two intake ports, X_1 and X_2, and two exhaust ports, F_1 and F_2, so as to balance the rotor radially. The rotation is counterclockwise.

The Vickers variable-delivery piston-type pump is shown in Fig. 15. This may be driven at motor speed directly to the shaft *A*. This rotates the driving flange *C*, which is mounted on heavy-duty radial and thrust bearings *B*. The driving flange is connected to the cylinder block *G* by a full-floating universal-joint shaft *D*. Connecting rods *E* are attached to the left end of the driving flange and are

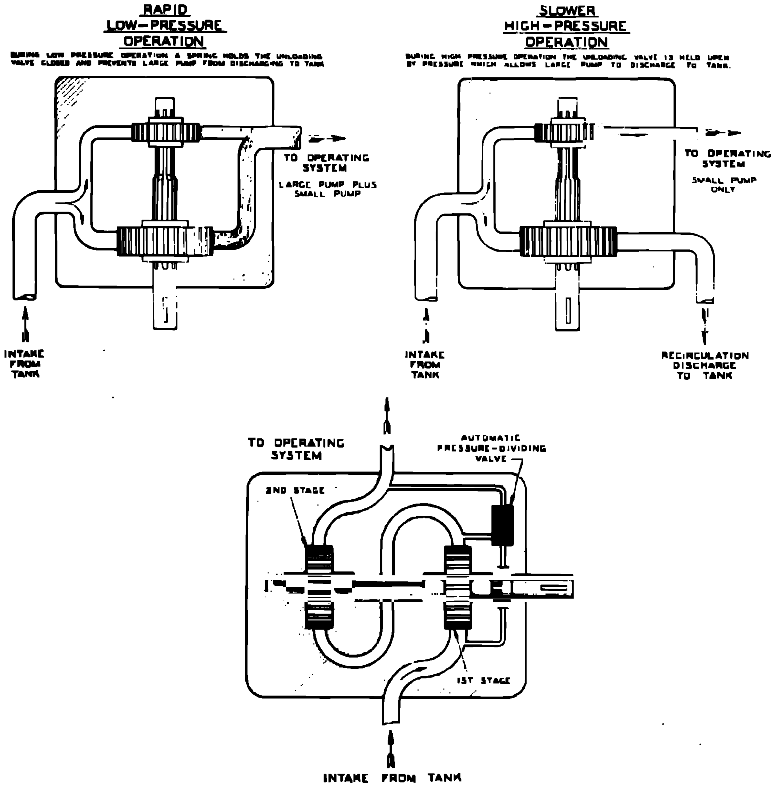
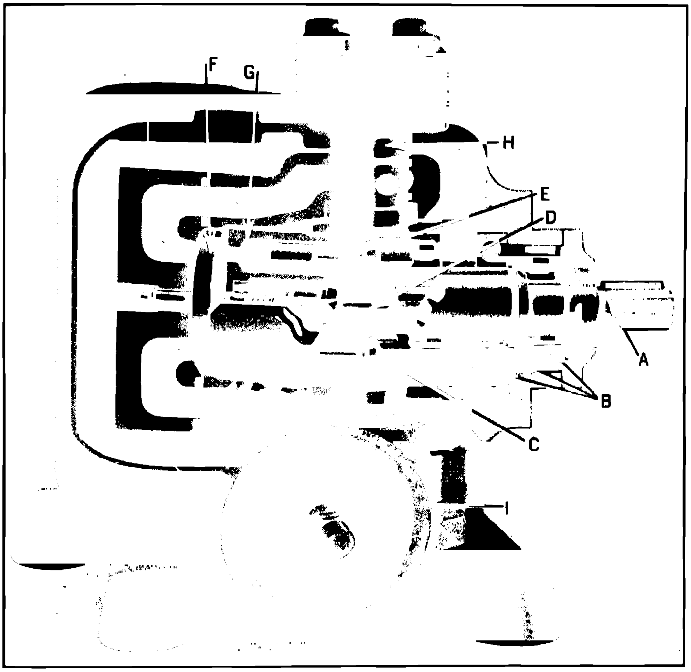

RAPID LOW-PRESSURE OPERATION
DURING LOW PRESSURE OPERATION A SPRING HOLDS THE UNLOADING VALVE CLOSED AND PREVENTS LARGE PUMP FROM DISCHARGING TO TANK
TO OPERATING SYSTEM
LARGE PUMP PLUS SMALL PUMP
INTAKE FROM TANK
SLOWER HIGH-PRESSURE OPERATION
DURING HIGH PRESSURE OPERATION THE UNLOADING VALVE IS HELD OPEN BY PRESSURE WHICH ALLOWS LARGE PUMP TO DISCHARGE TO TANK.
TO OPERATING SYSTEM
SMALL PUMP ONLY
INTAKE FROM TANK
RECIRCULATION DISCHARGE TO TANK
TO OPERATING SYSTEM
AUTOMATIC PRESSURE-DIVIDING VALVE
2ND STAGE
1ST STAGE
INTAKE FROM TANK

FIG. 14. The Vickers Combination Vane Pump at the Top Is Used for Rapid Low-Pressure and Slow High-Pressure Operations.

Below, the two pumps of equal size in series make a two-stage pump for increasing the hydraulic pressure.

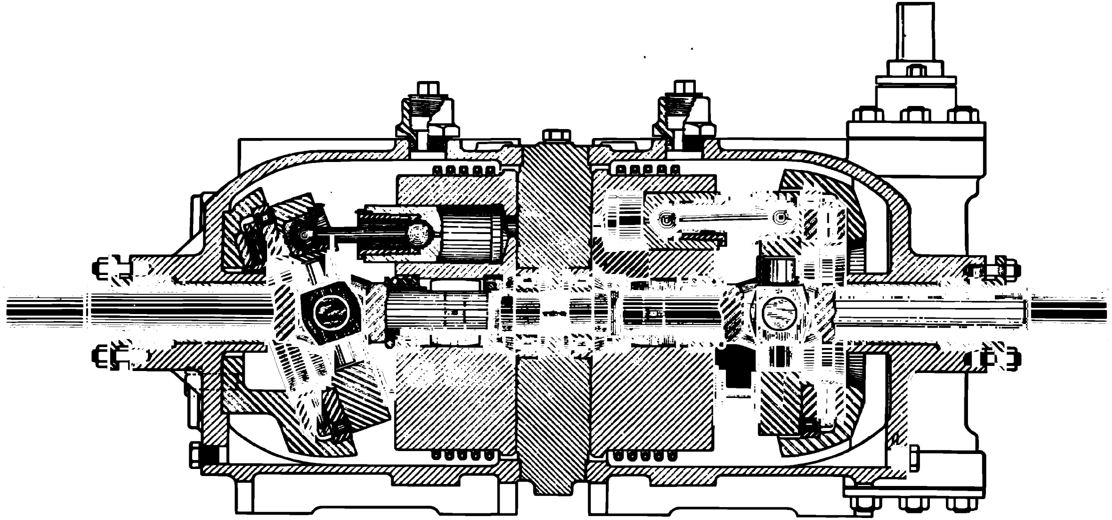
coupled to small pistons mounted in cylinders arranged axially in the cylinder block. The cylinder block bears against a valve plate *F* at its left end. This has ports so arranged that oil may be taken into the cylinders on the suction stroke and discharged on the pressure stroke through the hydraulically balanced pintles *H*, which support the housing in which the cylinders and valve plate are located. This housing may be swiveled about the axis of the pintles. When the axis of the cylinder block is coaxial with that of the driving flange, as the cylinder and flange rotate together, there is no travel of the pistons in the cylinders. Therefore, there is no discharge of the pump. As the cylinder block is swiveled about the pintles to the maximum extent, the travel of the pistons in the cylinder is greatest and the discharge of the pump is maximum. The angular position of the cylinders or pump yoke with relation to the driving axis is controlled manually by a hand wheel *I* as shown. The hand control may be replaced by a stem attached to a suitable mechanism or cam, a hydraulic cylinder, a pressure compensator, or a solenoid. Vickers also makes a positive displacement motor in which the angularity of the cylinder to the driving flange axis is fixed. As different amounts of oil are delivered to this motor, its speed is changed correspondingly.



Courtesy Vickers, Inc.

FIG. 15. The Vickers Variable-Delivery Piston-Type Pump.

Hydraulic variable-speed transmissions, consisting of a variable-delivery pump and constant-displacement motor, or a constant-delivery pump and variable-displacement motor, or both, are used



Courtesy Waterbury Tool, Div. Vickers, Inc.

FIG. 16. The Waterbury Hydraulic Variable-Speed Transmission with a Constant-Speed Variable-Delivery Pump at the Right and the Constant-Delivery Variable-Speed Fluid Motor at the Left.

The oil is transmitted through ports in the central block from the cylinders of the pump to the motor.

to provide rotating spindle drives on lathes and boring and honing machines, and for driving lead screws on large drilling and boring machines. Figure 16 shows the Waterbury hydraulic variable-speed transmission with pump and motor combined. The shaft at the right is driven at constant speed. A variable amount of oil will be delivered as the axis of the wobble plate is tilted from that of the rotating axis. This variable quantity of oil delivered to the fluid motor at the left in which the wobble-plate angle is fixed will produce a corresponding speed of the shaft at the left.

The advantages claimed by the use of hydraulic feed may be summarized as follows:

1. Flexibility of feed control.
   - (a) Any desired feed rate from almost zero to any required maximum.
   - (b) Automatic change of feed rate during the cut as desired, thus providing maximum metal removal.
   - (c) Any desired cycle of feed and quick traverse in either direction, together with automatic stop or feed change at any point.
   - (d) Possibility of feeding in a given direction until the table or slide encounters a positive stop, then dwelling to allow the tool to clear itself, after which the table automatically returns at a rapid traverse rate.
   - (e) Accuracy of trip because no clutches or other mechanical devices are employed.
2. Longer life of the power mechanism due to the fact that it is lubricated at all times by the fluid power medium oil.
3. Longer cutting life in broaching, drilling, and milling.
4. More metal removed per horsepower.
5. Greater feeds of drills and milling cutters and greater speeds in broaching.
6. Any degree of pressure according to requirements.
7. Perfect shock-absorbing qualities, permitting gradual acceleration or deceleration of load, and cushioning of impact loads.
8. Safety, as the entire feeding transmission may be safeguarded against overloading by various relief and control valves.

Pneumatic circuits are also used alone or in conjunction with hydraulic or electric controls in the operation of machine tools (*Product Engineering,* June, 1940, pp. 248 and 255).

QUESTIONS

1. What is meant by group drive?
2. Why has individual drive replaced group drive?
3. What is meant by the drive of a machine table if it is: (a) mechanical, (b) hydraulic, and (c) hydraulic but electrically controlled?
4. Give the specifications of a 5-hp a-c squirrel-cage induction motor such as one used to drive a machine tool by flange mounting.
5. What is meant by a high-slip motor and what are the advantages of high slip?

6. What types of enclosures are provided for electric motor service?

7. What is meant by the full-load torque and at what speed does it occur?

8. Name and define some of the accessories available for electric motor control.

9. Name two principal types of mechanically operated variable-speed transmissions.

10. Explain the difference between metering-in and metering-out.

11. Explain the difference between the action of a gear pump, a vane-type pump, and a piston variable-delivery pump.

12. When is a constant-delivery pump used instead of a variable-delivery pump?

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CHAPTER XX

ACCOUNTING AND COSTS

Usually all bookkeeping for a business is done in a central office called the accounting department under the direction of an auditor, controller, or treasurer, Fig. I-2. Accounting consists of keeping records of all financial transactions, such as investments, loans, purchases, and payment of wages, together with a complete record of sales, administrative, and manufacturing expenses.

The accounting department serves the business in several ways by submitting to those in charge of the management reports which show the state of the company's financial condition, the income and expenses, the distribution of expenses, and the general trend of the business. A balance sheet is usually made up annually to show the assets and liabilities of the company in itemized form. Under assets are listed cash, accounts receivable, inventories, bonds, land, buildings, etc. Under liabilities are listed accounts or notes payable, stock issued, etc. An income and expense sheet shows gross sales, cost of sales, net sales, etc., leading to the net profit for the period. This report may be issued quarterly or semiannually with a summary for the year.

Other reports dealing with the sales, administrative, or manufacturing departments, which, by indicating the trend of the business, assist in its direction, may be issued as needed. For example, a statement issued each month to the manufacturing department for its guidance gives the cost of direct and indirect labor, supplies, tools, repairs, supervision, heat, light, power, labor turnover, etc., as well as the fixed charges (those which remain the same regardless of the amount of production) such as interest on money invested, depreciation, taxes, insurance, rent, etc., and also data on amounts of production. All such manufacturing expenses, except the fixed charges, are controlled directly by the head of the department. It is only by knowing what they are from month to month that they can be regulated. The report of manufacturing expenses is often shown by departments and totaled for the whole factory so that the detailed distribution may be analyzed to better advantage.

All expenditures of a small industry may be grouped under five main heads, as shown in Fig. 1.

The factory payroll may be divided into two parts: direct and indirect labor. **Direct labor** is that which can be charged directly to a piece being manufactured as a product. This is an outgrowth of the term productive labor which may be defined as that consumed in changing the form of the part produced or assembling one part with another. **Indirect labor** is that which is neither direct nor productive. It is thrown into the **factory overhead,** or burden, which represents all expenses difficult to charge directly to the product.

The factory materials and supplies also may be divided into direct and indirect material. **Direct material** may be defined as that material which enters into the product. All other material items, such as supplies, tools, and jigs, are **indirect** and become overhead. The material of column 2, Fig. 1, is separated into direct and indirect.

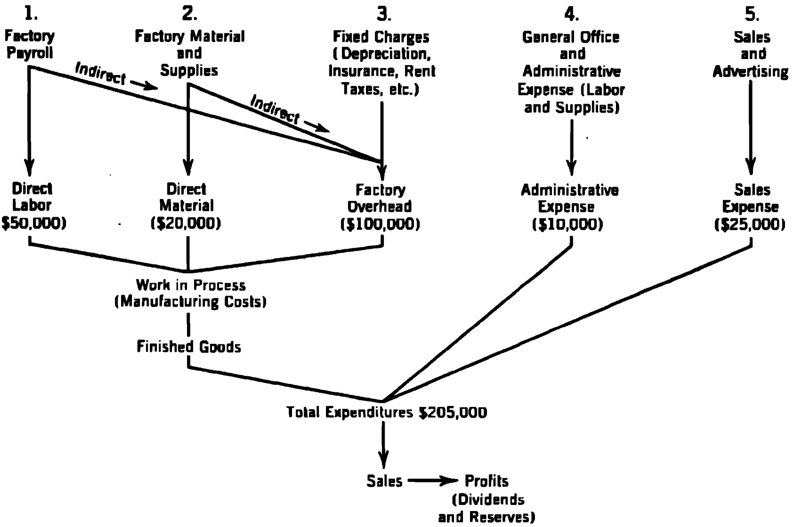
1.
Factory Payroll
2.
Factory Material and Supplies
3.
Fixed Charges (Depreciation, Insurance, Rent Taxes, etc.)
4.
General Office and Administrative Expense (Labor and Supplies)
5.
Sales and Advertising
Indirect
Indirect
Direct Labor ($50,000)
Direct Material ($20,000)
Factory Overhead ($100,000)
Administrative Expense ($10,000)
Sales Expense ($25,000)
Work in Process (Manufacturing Costs)
Finished Goods
Total Expenditures $205,000
Sales
Profits (Dividends and Reserves)

FIG. 1. Distribution of Total Expenditures for a Month.

Machine tools are purchased as capital accounts and are charged into operating expense against production as depreciation, obsolescence, repairs, interest on investment, insurance, and taxes. The **depreciation** represents an amount which, when set aside each year during the life of the machine, will provide a fund with which it may be replaced. This may run from 1–5 years for single-purpose, high-production machines to 10–20 years for standard machines. **Obsolescence** represents an amount needed to replace the machine which has been superseded by new processes or improved design. Cutting tools, jigs and fixtures, dies, etc., usually are charged against operating expense at their whole value during the first year. This represents 100 per cent depreciation. Sometimes tools of this type are charged entirely against the particular job for which they are purchased, even though the job lasts for a period less than one year.

Columns 4 and 5, Fig. 1, become administrative expense and sales expense, respectively. Selling expenses are entirely a cost of selling. Administrative expenses represent a service partly to selling and partly to production, and include accounting work, treasury, paying employees, etc.

The direct labor, direct material, and factory overhead combined cover the value of the work in process which leads to finished goods. The total cost then is represented by the factory or **manufacturing cost** of the finished goods plus **administrative** and **sales** expenses.

Divisions of Accounting

Accounting may be divided into two parts: general accounting and cost accounting. **General accounting** includes everything as described above, except that included in cost accounting. **Cost accounting** is confined to the compilation of data leading to direct-labor costs, direct-material costs, manufacturing costs, and list prices. The proportions of the factory overhead and administrative and selling expenses to be carried by each part are determined in the general accounting office and subsequently used for cost determination so that there is a close relation between the two divisions.

Cost accounting: When the product being sold by an industry is made up of a number of parts, it is desirable that the cost of each part be known. The total cost of a part (**unit cost**) is made up of its direct-material cost, its direct-labor cost, and a proportion of each of the factory overhead, administrative expense, and the sales expense, Fig. 2. The selling price equals the total cost plus a profit. The list price of a part equals the selling price plus an additional arbitrary amount to insure that the list price is always higher than the selling price as the total cost varies from month to month. This is for convenience in showing the price of an article in general catalogs. The discount can be changed on short notice by issuing revised discount sheets rather than reprinting the literature containing the list prices. To illustrate, the list price of a 1-in.-diam. high speed steel twist drill with No. 3 Morse taper shank is $10.25. The current discount is 40 per cent. Steel, on the other hand, is usually sold at a certain base price per pound with extras added for size, annealing, cutting to length, etc.

Apportioning overhead and expenses for unit costs: The direct-labor and direct-material costs of a part are quite definite, and together give the **direct cost** of a part. The proportions of the overhead and expenses carried by each part vary widely with the method used in distributing them. To obtain reasonably accurate unit costs, that part which requires most overhead and expense in its manufacture should carry a greater proportion in its cost.

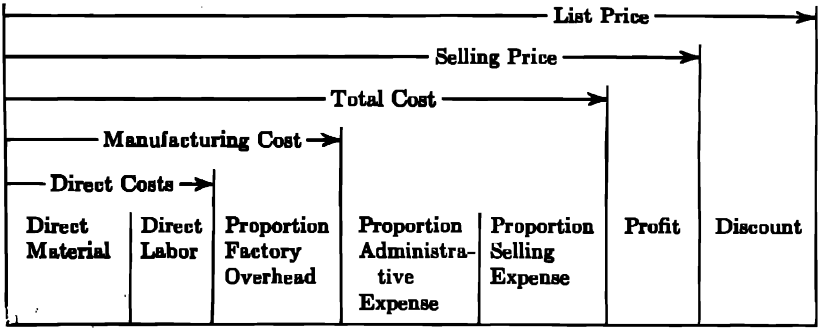

FIG. 2. The Factors Which Make Up the Unit Cost of a Part.

Some methods in general use for apportioning overhead are as follows:

1. Overhead as a percentage of direct-labor wages.
2. Overhead as a percentage of direct-labor hours.
3. Overhead as a machine-hour rate.
4. Overhead broken down into departmental overhead and subsequently apportioned.

The first is possibly the oldest and most common vehicle for distribution of overhead to product. If a single percentage for the entire plant is used, its application is as follows: If the overhead for a month is $100,000 and the total direct-labor cost is $50,000, then the burden in percentage of direct labor is 200 per cent, so that in order to absorb it, each dollar of direct labor must carry 200 per cent of itself as its share of the total burden. Assuming that labor cost for a part is 10 cents, material cost 4 cents, and burden 200 per cent of labor, the manufacturing cost is 10 cents + 4 cents + 20 cents = 34 cents. By this uniform overhead method the same amount of overhead is charged against a given amount of labor for all pieces. One piece may require equipment having little overhead in the form of investment, floor space, power, maintenance, supervision, etc., such as a workbench and vise valued at $50. Another piece may be produced on an expensive machine such as a Mult-Au-Matic turning machine representing an investment of some $38,000. The machine is driven by a high-powered motor and requires considerable maintenance. If the same number of all parts were sold during the year, this method would be simple and satisfactory. Where the product is diversified and the sales unbalanced, the resulting gross sales might vary a great deal above or below the sales of Fig. 1. Administrative and sales expenses are added on a basis of 10 and 25 per cent, respectively, to obtain total unit cost.

The direct-labor hour is sometimes used instead of direct-labor wage, because in some cases it is found that hours are more stable and satisfactory than wages.

The machine-hour rate is commonly used and is probably the most accurate method of distributing overhead. A rate per hour is determined for each machine so that more overhead is charged against a given amount of labor on a large automatic screw machine than on a small drill press, the direct labor charge per piece being the same in each case.

In the fourth method, items of overhead are accumulated by departments. Those of general overhead departments are allocated to the service and production departments according to the responsibility of each for its incurrence. The apportionment, in turn, of the overhead of the service departments is made to the production departments for which the several service centers are maintained. When this has been done, all the overhead of the plant has been applied to production.

There are two radically different methods of ascertaining costs, i.e., to determine them after the work is completed, as illustrated by the examples given above, and to estimate them before the work is undertaken. This second method, known as **standard costs,** is based on material costs and labor and overhead rates taken from predetermined standards, or estimated in conference by the production engineer, superintendent, rate setter, tool supervisor, foreman, etc. Standard costs are set up and modified from time to time as experience indicates.

Mechanization

The **reduction of labor costs** has been the impetus of a development of machine tools, jigs and fixtures, dies, and small tools, which is still gaining momentum. Automatic equipment and standard equipment, provided with tools for high production, usually are more expensive than manually operated devices, are more complicated in design, require more care and time in setting up, and have higher maintenance costs. Despite these apparent disadvantages, the work of automatization proceeds apace, and manufacturing costs continue to decline.

Each worker in United States manufacture is assisted with equipment valued at approximately $7,500. This figure is increased to about $14,000 in the automotive industry. Through the increase in capital investment, the labor cost is materially reduced. This lowers the manufacturing cost and makes the products available to a much larger number of individuals.

When the manufacture of a part is under consideration, the number involved is of paramount importance. The manufacturer must provide himself with machines, special fixtures, dies, tools, and gages to facilitate production at the lowest cost. Small-lot production does not justify high expenditures for automatic machine tools, special tools, jigs and fixtures, etc., whereas mass production may support a very high investment. Such jobs must be analyzed on the basis of their own merits as there is just as much danger of spending too much for equipment and accessories as there is in undertooling.

A part may be machined in 120 min, floor to floor, in an engine lathe costing $4,000, or in 6 min in a turret lathe costing $8,000. The direct-labor cost of production is $1.80 per hr for both, but it costs 90 cents in labor and tools to set up the lathe and $8 for the turret lathe. The machine load for the lathe is $1 per hr, and for the turret lathe, $2.60. The cost of making one piece on the lathe would be 2($1.80 + $1) + 90¢ = $6.50. On the turret lathe, it would cost 6/60($1.80 + $2.60) + $8 = $8.34. If ten parts were made, in each case the unit cost on the lathe would be $5.69, but only $1.24 on the turret lathe.

QUESTIONS

1. What are some of the duties of an accounting department?
2. Why should the cost department be a part of the accounting department rather than come under the jurisdiction of the factory manager?
3. What are fixed charges?
4. What is meant by direct costs? Explain the two elements.
5. What is meant by allocation of factory overhead?
6. Explain how manufacturing costs might be reduced through increased overhead.
7. Explain the difference between depreciation and obsolescence.
8. What is meant by accelerated depreciation and what is its purpose?
9. Explain the advantages of mass production in reducing unit cost.

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